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CORRECTION NOTICE

In Fig. 1, page 274, the figures 14 and 18 of the vertical axis should read 16 and 20, respectively.

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THE PRODUCTION AND USE OF COCKSFOOT FOGGAGE FOR WINTER GRAZING IN SOUTH-WEST SCOTLAND

M. E. CASTLE AND J. N. WATSON

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The production and use of cocksfoot foggage for winter grazing at the Hannah Dairy Research Institute in the period 1956–61 is described. Two acres of cocksfoot (S37) were sown broadcast in 1956 and two acres were drilled in rows 28 in. apart in 1957. The average annual application of fertilizer nutrients was 118 lb. N, 51 lb. P_2O_5 and 142 lb. K_2O per acre.

The mean yield of the broadcast section was 7450 lb. dry matter/acre/annum compared with 6090 lb. from the rowcrop section. Normally two crops of grass were harvested from the field in the summer, and one grazing was made in the winter. The yield of winter herbage dry matter was 28% and 26% of the total annual yield of the broadcast and the rowcrop sections, respectively.

The field was grazed for four successive winters by 5–10 bulling heifers each weighing 650–850 lb. They received no other feed during the grazing period. Grazing started in December and finished in February, March or April in different years. The mean intake of herbage dry matter was only 6 lb./day, and on average the heifers lost 80 lb. liveweight each winter. This loss was regained after 4–6 weeks when the winter grazing finished. Twenty-nine of the 30 heifers held to the first or second service while grazing the winter herbage.

On average the broadcast section gave 340 heifer-grazing-days per acre during the winter and the rowcrop section 260 days. The cost of a heifer-grazing-day was 3½d. and 4¼d. on the broadcast and rowcrop sections, respectively.

The dry matter of the herbage cut on 19 December 1960 had a digestible crude protein content of 5·9% and a starch equivalent of 34.

It is concluded that on well-drained land the technique of foggage production and of winter grazing can usefully extend the normal grazing season and hence reduce the costs of winter feeding.

INTRODUCTION

Grassland is normally conserved for winter use as hay, silage and, to a lesser extent, as artificially dried grass. All these conservation products are, however, considerably more expensive per ton of starch equivalent than grazed herbage (1) so that methods of extending the grazing season and placing less reliance on conserved grass crops for stock-feeding should reduce feed costs. The technique of producing 'early bite' spring herbage (7) is now fairly common, but on most farms far less attention is paid to the production of late autumn and winter herbage. The extension of the grazing season into late autumn and winter by conserving herbage on the field ('foggage' production), is not new (6) and the experimental production and utilization of foggage has been successfully demonstrated by Hughes (10, 11, 12) and Corbett (3, 4, 5). The encouraging results of the small-plot trials of Gardner (8) and Gardner and Hunt (9) suggested that the growing of foggage in south-west Scotland was an economic possibility; this paper reports the results of a field-scale trial on the production and use of cocksfoot foggage.

EXPERIMENTAL

Establishment of the sward

The 4-acre field selected for the trial was about 100 ft. above sea level and had a gentle slope facing towards the north. The soil was a light loam overlying a sandy subsoil and at the start of the trial it had a pH of 6·3. After the normal cultivations to prepare a fine tilth, a seedbed application of 3 cwt./acre of a compound fertilizer (12 N, 4 P_2O_5, 12 K_2O) was made and the seed was sown on 6 April 1956. The field was divided into two 2-acre parts. On one section cocksfoot (S37) was broadcast at 14 lb./acre, while on the other section the cocksfoot was sown in drills 28 in. apart at

12 lb./acre. The establishment of the broadcast cocksfoot was excellent and competition from weeds was low, but on the rowcrop section the large area of bare ground between the rows of cocksfoot seedlings encouraged the growth of weeds and in spite of spraying and inter-row cultivations the cocksfoot plants were dominated by the weeds and unsown grasses. In order to obtain a better establishment of cocksfoot in rows for comparison with the broadcast section the rows were ploughed up in June, 1956, two applications of Tecane* were made and the rows were resown on 1 May 1957 at 8 lb./acre. On this occasion the cocksfoot became well established and only a few annual weeds were present; these were largely removed by inter-row cultivation and by grazing with sheep. Throughout the trial, therefore, the broadcast section was 1 year older than the rowcrop section. The management of the broadcast and the rowcrop sections in the seeding year was aimed at establishing vigorous plants of cocksfoot, and in order to do this further applications of fertilizer were made and a system of on-and-off grazing was practised.

Summer management

After the seeding year the summer management was similar for both the broadcast and rowcrop sections. In early spring the field was severely chain-harrowed, to spread the dung, and rolled; phosphate and potash fertilizers were applied. This was followed by a dressing of 2–3 cwt./acre of nitro-chalk (15·5% N) in early April. Similar applications of nitrogen were made after each grazing or silage cut. The final application of 2–3 cwt./acre of nitro-chalk was made in the first week of August each year and after that date the field was rested until the winter grazing started. That date for 'putting-up' the field is considered by Gardner and Hunt (9) to be the optimum for this area.

The mean weights of fertilizer nutrients applied each year are summarized in Table 1. In any one year identical amounts of fertilizer nutrients were applied to both sections, but the amounts varied from year to year. The slightly higher mean values for the broadcast section are due to the unequal weights which were applied on the two sections of the field in the seeding year.

TABLE 1. Mean weight of fertilizer nutrients applied per year, including the seeding year

Fertilizer nutrient (lb./acre)	Section of field	
	Broadcast	Rowcrop
N	121	116
P_2O_5	52	50
K_2O	145	138

Winter management

The grazing of the winter grass was mainly by Ayrshire heifers of about 2 years old. In previous years this class of stock were out-wintered and fed hay and grass silage, but during the four winters of the experiment the heifers had the winter foggage as their sole feed and *no* other supplementary feed was given regardless of the weather. A young Ayrshire bull was kept with the heifers each winter, except for the last one when any heifers in season were served by a bull indoors. Occasionally a few dry cows joined the group but the largest proportion of the grazing was done by the heifers alone. Their number varied from 5 during the 1958–59 winter to 10 in 1959–60.

The heifers grazed behind an electric fence which was moved once, or occasionally twice, each day. The length of the grazing face was 485 ft. and each heifer therefore had on average a length of 48 to 97 ft. to graze.

Records and costings

Detailed records of all work done on the field were kept. The horse-, tractor- and man-hours were charged each year at the appropriate current rate and the rent of the field and the share of the overhead farm costs were also charged. All herbage cut on the field in the summer was weighed and samples were taken for the determination of dry-matter content. In addition regular samples were taken during the winter to calculate the dry-matter intake of the animals.

*A weed killer based on T.C.A., trichloroacetic acid.

RESULTS

Herbage yields

The herbage yields are summarized in Table 2.

TABLE 2. Mean annual yields of herbage and the number of grazing days in winter

	Section of field	
	Broadcast	Rowcrop
Yield of dry matter (100 lb./acre/year)	74·5	60·9
Yield of winter herbage dry matter as a percentage of total yield	28%	26%
Number of heifer-grazing-days per acre in winter	340	260

The mean yield of the broadcast section, 7450 lb. dry matter/acre, is satisfactory and compares favourably with yields from other cocksfoot leys on the same farm which had normal management. For example, between 1954 and 1958 a mean annual yield of 8090 lb. of dry matter/acre was recorded from a cocksfoot ley which was given 158 lb./acre/year of fertilizer nitrogen (2). In the present trial only 121 lb./acre of nitrogen was used (Table 1). The rowcrop cocksfoot yielded approximately 20% less dry matter/acre than the broadcast cocksfoot. This is attributed to the wide spacing of the drills (28 in.) which resulted in a much lower population of cocksfoot. A point quadrat botanical analysis at ground level on 17 February 1961 showed that the broadcast section had a ground cover of 70% cocksfoot whereas the rowcrop section had only 36%. On both swards the remaining area was mainly bare ground. A narrower spacing of the drills with a resultant increase in the amount of cocksfoot would no doubt have increased the yield of the rowcrop section. Gardner (8) recorded a greater yield from cocksfoot in rows than when broadcast, but in his trial the rows were 21 in. apart.

The yield of dry matter varied from year to year from a minimum of 4420 lb./acre on the rowcrop section in 1957 to a maximum of 8810 lb./acre on the broadcast section in 1958. These differences were due partly to the method of sowing, as previously described, but the major differences were attributable to the amount of fertilizer nitrogen applied in the different years. On average the return from each extra 1 lb. of fertilizer nitrogen was 19·7 lb. of dry matter. This response is similar to that recorded in other field-scale and plot trials at this Institute (2).

Summer utilization of herbage

Two crops of herbage were harvested from the rowcrop and the broadcast cocksfoot during each summer of the experiment, with the exception of 1958 when three were taken. The first growth was normally cut for silage and the earliest and latest dates of cutting were 22 May 1959 and 3 June 1958, respectively. The mean crude-protein content of the dry matter in the silage cuts was 11·9%. The second growth was grazed by young stock and dry cows.

Winter utilization of herbage

The dates of the winter-grazing periods are given in Table 3. In October and November 1956 the grazing of the broadcast section was purposely completed early, as the sward was in its seeding year and it was thought that later grazing might damage the sward. Similarly in 1957 the rowcrop section was grazed before the broadcast section, although in the later years this order of grazing was reversed. It will be seen from Table 3 that grazing started in December and was completed between 24 February and 9 April in the different years. The mean number of heifer-grazing-days/acre

TABLE 3. Dates of grazing of the winter herbage

Winter period	Section of field	
	Broadcast	Rowcrop
1956–7	20 Oct. — 9 Nov.	—
1957–8	21 Dec. — 5 Feb.	2 Dec. — 20 Dec.
1958–9	8 Dec. — 5 Jan.	6 Jan. — 11 March
1959–60	23 Dec. — 18 Feb.	19 Feb. — 9 April
1960–1	7 Dec. — 12 Jan.	13 Jan. — 24 Feb.

during the winter months is given in Table 2. These outputs are high, but the winter herbage was rationed very severely and the average daily intake per animal was only 6 lb. of dry matter. The utilization of the winter herbage was virtually complete; this was accomplished by the strict rationing of the animals by using an electric fence and having a long and narrow grazing face at the fence. At times when the fence was moved twice a day, all the grazing was done by the animals under the fence and no ungrazed herbage was damaged or soiled by treading or contamination with dung and urine.

Snow fell during three of the four winters and covered the ground either completely or partially for 6 days in 1957/58, 6 days in 1958/59 and 14 days in 1959/60. The maximum depth of the snow was 6 in. in February 1960, but at no time was it an obstacle to the cattle. Grazing continued normally and the heifers merely brushed the snow aside with their noses.

Animal performance

The liveweight changes of the heifers during the four winters are shown in Table 4. The daily liveweight changes varied from year to year, and as in the work of Hughes (12) they reflected the amount of herbage available and the area of grazing allowed per day. On average there was a loss of 80 lb. per animal. When the winter grazing was completed, the heifers were either fed grass silage *ad lib.* in another field or started grazing an early bite of Italian ryegrass. Liveweight gains were made rapidly and, as seen in Table 4, the original liveweight at the start of the winter grazing period was regained within a period of 29–44 days. It is impossible to state what proportion of the liveweight changes were due to changes in rumen 'fill', but without doubt some of this rapid increase in weight could be attributed to this cause. The condition of the animals was good at the start of the winter-grazing period and remained so throughout the winter and the loss of liveweight was not obvious. In the four years of the trial, 29 of the 30 heifers held to the first or second service. This is an excellent breeding record and compares favourably with that obtained on other systems of winter feeding.

Costs

The average cost of producing the herbage is detailed in Table 5. On both sections of the field the fertilizer costs were high and amounted on average to 43% of the total cost of producing the herbage. The allocation of the cost of the winter herbage was based on a proportion of the costs of the total yield, using the percentage values in Table 2.

TABLE 5. Average cost per acre of growing the herbage (£ per annum)

	Section of field	
	Broadcast	Rowcrop
Rent	3·0	3·0
Share of farm overheads	4·0	4·0
Share of cost of establishing sward	1·4	1·7
Fertilizer (less subsidy)	8·0	7·2
Harrowing, rolling and spreading fertilizer	1·8	1·4
Total	18·2	17·3
Cost of the winter herbage	5·1	4·6
Cost of a heifer-grazing day in winter	3½d.	4½d.

TABLE 4. Liveweight changes of the heifers on the winter herbage

Winter period	Liveweight (lb.)			Number of days required after the end of the winter grazing to regain the original liveweight
	At start of grazing	At end of grazing	Loss	
1957–8	858	779	79	29
1958–9	700	655	45	34
1959–60	736	622	114	31
1960–1	792	710	82	44

Nutritive value

The nutritive value of a sample of the winter herbage was determined in a conventional digestibility trial using an Ayrshire-Galloway cross steer aged 18 months. An area of the broadcast cocksfoot was cut on 19 December 1960, dried to an average moisture content of 4% and offered at a constant level of feed intake of 12 lb./day. The average dry-matter intake was 10·0 lb./day and the composition of the herbage dry matter was 11·9% crude protein, 3·8% ether extract, 32·2% crude fibre, 42·1% nitrogen-free extractives and 10·0% ash. Samples of the herbage were handsorted before drying and contained 39% of green herbage and 61% of 'burn', on a dry-matter basis. The starch equivalent of the herbage dry matter was calculated from the content of digestible nutrients and the starch conversion factors quoted by Woodman (14) and was 34. The digestible-crude-protein content of the dry matter was 5·9% but both this value and the starch equivalent may be subject to errors, as the digestibility trial was conducted on only one animal.

DISCUSSION

This trial, conducted in south-west Scotland, has given results which in general agree well with those of Corbett (3, 4, 5) working in Aberdeenshire and Hughes (10, 11, 12) in Warwickshire. The production of winter herbage by applying a nitrogenous fertilizer in early August and resting the field until required was a simple, cheap and reliable technique. The cocksfoot used proved eminently suitable, fully confirming the recommendations of Gardner (8).

The winter herbage was eaten readily by the stock and on no occasion was any other supplementary feed offered. The quality of the winter herbage was comparable to a meadow hay between the flowering and the seed-set stage (13), and although it was severely rationed to the animals in our trial they were maintained in excellent condition. With a consumption of about 6 lb. of herbage dry matter/day the intake of starch equivalent was estimated to be only 2 lb./day. This is well below the recommended level for maintenance purposes (14) and consequently there was a loss of liveweight. However, this loss was quickly and cheaply made up in the spring, when early grazing was available, and the stock did not appear to suffer any permanent setback. The heifers calved normally in the autumn and the milk yields of the animals which were used in the first three winters of the trial were satisfactory and averaged 8150 lb./heifer.

The winter grazing had no detrimental effect on either the rowcrop or the broadcast swards and the productivity of the ley showed no sign of decreasing with age. The silage cuts taken from the swards in the spring were as early as any other on the farm and, as described earlier, the ley proved to be exceptionally responsive to dressings of fertilizer nitrogen.

The yields of dry matter and the number of grazing days were higher from the broadcast than from the rowcrop area. This difference in yield was due primarily to the wide spacing of the rows; a distance of 28 in. between the rows was clearly too wide, and 21 in. or less would appear to be preferable. The cocksfoot plants grown in the rows were more upright in the winter months than the broadcast ones and appeared also to be more palatable. It is claimed that on some soils the animals walk between the rows and hence reduce the amount of poaching. On our light soil there was little or no damage even on the broadcast section but on many soils rows would be preferable to a broadcast sward.

It is not claimed that cocksfoot left *in situ* as winter grazing is a suitable feed for milking animals, but for dry stock and bulling heifers it has proved to be a cheap and useful feed. An average of two heifers aged 21 months have been kept on one acre for about 3 winter months, and this extension of the grazing season has had no depressing effect on the total production of the sward. If a cheap and simple method of wintering is required and the land is suitably well-drained, the methods described in this paper are well worth a trial.

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A REVIEW OF SILAGE-MAKING TECHNIQUES

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One of the main problems associated with silage-making is the wastage which occurs through either the use of unsuitable silos or lack of care in filling the silo. The nutrient losses caused by waste can be very high, a fact which is seldom recognized, and it is imperative that wastage should be kept to a minimum. There need be very little side-waste when a container silo is properly filled, but surface waste is more of a problem, as applying and removing conventional sealing materials, such as soil or ground limestone, are laborious and costly. In many cases, however, the cost would be amply justified because of the quantity of silage which is wasted. Using plastic sheet as an airtight seal is a possible alternative, but it is not easy to ensure that it is completely airtight and the sheet is unlikely to be of use for more than one season. An increasing number of farmers are protecting their silage with permanent roofs, a practice which will lead to a general improvement in silage quality. Theoretically, however, the hermetically-sealed tower silo is ideal from the point of view of protecting silage. The cost of this type of silo and of the ancillary equipment required is prohibitive, and it remains to be seen whether a relatively cheap form of gas-tight silo can be evolved.

In future it is likely that the recommendation to allow a temperature rise to 90–100°F in silage will be ignored, as results from a number of trials clearly show that there is no advantage in doing this. Continuous filling of the silo, rather than filling in layers and allowing the mass to heat up, will allow a greater quantity of herbage to be ensiled in a given time, thus making it easier to ensile the herbage at the correct stage of growth.

In the past when an additive was used it was applied by hand, a very inefficient method of distribution. Silage-making has become highly mechanized, and it is likely that mechanical application of additives will become much more popular.

The importance of the dry-matter content of the herbage being ensiled will be more generally recognized. There are many benefits in pre-wilting herbage before it is ensiled, and this treatment is well worth consideration. It is obviously undesirable to have a prolonged wilting period, and one technique which may be of some interest is cutting the crop with a flail-harvester, allowing it to wilt and then picking up with a harvester. Cutting with a harvester gives a very much increased drying rate of the herbage, and the double lacerating action of the harvester in cutting and picking up results in short material which is easily handled and consolidated.

Several reviews on making and feeding silage have been published in recent years, the latest being a comprehensive survey of the literature by Watson and Nash (51). Another excellent review by Breirem and Ulvesli (4) fully covers the aspect of adding acids to silage and also deals with some of the factors influencing silage quality. Carter (8) has reviewed the literature, mainly American, on the comparative nutrient losses in silage and haymaking. There is little point in covering the same ground as in these reviews, and only recent developments which are of some practical interest will be mentioned here.

The nutrient loss in silage-making

Losses are incurred by plant respiration, bacterial fermentation, seepage from the silo and wastage. Generally, these losses, with the exception of wastage, are assumed to be unavoidable, although some ensiling techniques can reduce the quantity of seepage from the silo. Under experimental conditions the unavoidable losses will be in the order of 15–20% of the dry matter, 20–25% of digestible crude protein and 25–30% of the starch equivalent (51). When very small silos have been used for experimental work, dry-matter losses have sometimes been very low, often in the range of 5–10%, presumably because of the strict control which can be exercised when small quantities of silage are made. There is a wide discrepancy between these experimental results and those reported from trials in which farm-type silos were used. At Jealott's Hill losses of 32% and 51–64% of the dry matter

took place in pit and stack silos, respectively (51). A New Zealand trial comparing pit, covered and uncovered stack silos showed dry-matter losses of 28%, 42% and 52% for the three types of silo (40). Losses of dry matter in a pit silo and small tower silos in a trial at Aberdeen averaged 42% and 40%, respectively (15). Recent trials on N.A.A.S. Experimental Husbandry Farms have shown that high losses can take place, being on average 26% of the dry matter in walled silos and 39% in unwalled silos (10). These losses compare unfavourably with those obtained in N. Ireland (5, 6), where the dry-matter loss in lined trench silos was 22–26%, and also with results obtained in American trials with tower and bunker silos (dry-matter loss in the range of 10–22%) (17).

Some of the discrepancy is possibly due to no correction being made for the loss of volatile substances in oven-drying the silage, but this cannot account for some of the very high losses which have been reported. It is probable that the difference in losses between experimental and farm-type silos is largely due to the degree of wastage taking place, and the New Zealand trials (40) clearly show that increasing dry-matter loss occurs in silos which are progressively unprotected. The data available indicate that even modest amounts of visible waste have a very marked effect on nutrient loss. These results emphasize the need to protect the sides and top surface of a mass of silage, as surfaces exposed to air will inevitably be subject to wastage and this will give rise to undesirably high losses of nutrients.

Factors affecting the fermentation in silage

In recent years there has been a considerable advance in knowledge of the factors which affect fermentation. The type of fermentation in silage is dependent on the type and number of bacteria present on the herbage and the conditions created by the herbage and ensiling technique in the silo. An exception to this is the A.I.V. method of silage-making, based on direct acidification of the mass, in which little or no reliance is placed on bacterial fermentation. Generally, however, the preservation of silage depends on lactic acid—a by-product of bacterial metabolism—being formed in the silage, and for this method to be successful the herbage ensiled, and the treatment applied, must give suitable conditions in the silo for the growth of lactobacilli. In addition, an adequate population of lactobacilli must be present on the herbage when it is ensiled. It is also important to keep proteolytic bacteria to a minimum, by avoiding contamination with soil.

The bacterial flora on the herbage

In the past it was generally assumed that lactobacilli were always present on green crops, but recently it has been shown that wide variations can occur in the number of these organisms present on herbage (44). There is some evidence that lactobacilli multiply during the wilting process (18), but work at Edinburgh indicates that type of crop, locality and seasonal variations have little effect on the numbers of lactobacilli present on herbage (44). Samples of herbage from grazed pastures all had an appreciable lactobacilli count, although it appeared that this effect was of short duration, as crops cut some time after grazing did not always contain lactobacilli.

The possibility of using an inoculum of lactobacilli, either by itself or with a carbohydrate additive, has been extensively investigated. Results have been variable, possibly due in some cases to unsuitable types of bacteria being used. In recent years several attempts at inoculation have proved to be unsuccessful (51), but at Edinburgh inoculation of laboratory silages with selected strains of lactobacilli has given good results when sufficient fermentable carbohydrate was available (45).

Some doubt still exists as to the reliability of inoculation on a farm scale, and in any case no suitable inoculum is generally available. At present, therefore, it must be assumed that sufficient lactobacilli are present on the herbage.

The sugar content of herbage

The importance of an adequate supply of fermentable carbohydrate as a source of nutrients for lactobacilli has long been recognized, and a recent laboratory trial has

emphasized this (45). An interesting side-issue to this trial was the demonstration of the effect of weather on the sugar content of herbage. It was found that in bright, sunny weather the sugar content of grass was much higher than in cloudy, overcast conditions.

A seasonal effect on the sugar content of grass cut at frequent intervals has been reported, less total soluble sugar being present in the later part of the year than in early summer (47), although there is a possibility that this effect may be due at least partly to the influence of weather which has been mentioned previously. No great difference in sugar content has been noted when there was a longer interval between cutting (21).

There is a considerable variation in the sugar content of different crops, and also between species of grass. Results from Sweden (46) show the wide variations occurring in the total sugar content of crops, and the subsequent effect on silage fermentation; lucerne and clover have a particularly low sugar content. It has also been shown that marked differences in the water-soluble carbohydrate content exist between species of grass, ryegrass having a high and cocksfoot a low content of sugar (47). There is also the interesting possibility of breeding strains of grass with an inherently high sugar content (9).

There is some evidence that high rates of fertilizer application can decrease the content of water-soluble carbohydrates in grass (48).

These factors which influence the sugar content of herbage are of considerable importance in silage fermentation, and give some explanation as to why certain types of herbage are more difficult to ensile than others.

The moisture content of the herbage

It is now well known that the moisture content of herbage has a marked effect on the fermentation in silage. It has been clearly demonstrated that pre-wilting of the herbage will result in a satisfactory silage, while the same herbage ensiled unwilted may produce a poor silage (30, 42, 55). No satisfactory explanation of this effect has been given until recently, as wilted silage generally has a fairly low lactic-acid content and relatively high pH value, and yet butyric-acid formation and protein degradation were low (30, 35). Recent trials in Holland indicate that the higher osmotic pressure in wilted silage has an inhibitory effect on proteolytic bacteria, and this could explain the better preservation occurring in wilted silage (53).

Pre-wilting the herbage has several other advantages. Nutrient losses are of a low order (30, 35, 42), except where there is an appreciable amount of waste because of the greater difficulty in consolidating the wilted herbage (30). The lower nutrient loss is at least partly due to the decrease in seepage from the silage (27, 35), since little or no seepage will take place when the dry-matter content of the herbage ensiled is 30% or more. On the other hand some loss of nutrients can be expected while the crop is wilting in the field, but this loss will be small (38) and, indeed, some gains in weight of dry matter have been recorded (34). An extended wilting period, or rain falling on the herbage in the field will, however, increase the losses during field drying (13). In general, however, the field losses will be more than outweighed by the lower losses occurring in the silo.

Another advantage of wilted silage is that a higher dry-matter intake can be expected when this type of silage is fed *ad lib.* than when a silage with a higher moisture content is offered (30, 41). It appears, however, that water in silage is not *per se* the cause of this difference in intake, and it is possible that some metabolite is present in low-dry-matter silage which may affect the appetite of the animal (25).

Water getting into the silage during the storage period can also have a marked effect on silage quality (26). The effect of rain entering the silage is to leach out the lactic acid, allowing a secondary and undesirable fermentation to take place, and there will also be increased nutrient losses due to the increased seepage taking place from the silo.

The mechanical treatment of the herbage

When the crop is chopped or lacerated by using a forage harvester or a stationary chopping machine, a better fermentation can

take place than when the herbage is ensiled unchopped (28, 33). A higher bacterial count has been found in silage made from minced grass than from uncut grass (43), and it has also been shown that a more vigorous lactic-acid fermentation occurs in chopped or lacerated silage than in unchopped (28).

Chopped or lacerated grass will be easier to consolidate in the silo than unchopped herbage, and it has been suggested that the effect on fermentation may not be due to the bruising of the herbage, but to the lower temperatures in the mass resulting from better consolidation (19). It appears, however, that the lower temperatures in the silage and the liberation of cell sap by mechanical bruising of the herbage can both influence the fermentation (52).

In some cases there has been a progressive improvement in fermentation with increasing severity of bruising (14). Results have been variable, possibly due to the difference in temperature in the silages being compared, and in one case, where similar temperatures were obtained, there was no difference in fermentation between severely bruised silage and that made with a flail-harvester (39).

The effect of temperature

It has been customary for many years to advocate a temperature rise to 90–110°F in silage, as it was supposed that there was less risk of a butyric acid fermentation in this temperature range (24, 41, 50). While butyric acid is rarely formed when very high temperatures occur in the mass (over 120°F), there is a marked decrease in the feeding value of the silage, particularly in the digestibility of the protein fraction (51), which appears to be a result of the combined effect of heat and oxygen present in the silage (53). At a lower temperature range (90–110°F) the feeding value of the silage is not impaired. This temperature range, however, does not necessarily create conditions favouring the development of lactobacilli, as both lactic- and butyric-acid-producing bacteria have a similar optimum temperature for growth (51).

"Cold" fermentation has been advocated for many years in Europe, but there has been little precise evidence on the value of this technique. In recent years a considerable amount of work has been done on this subject, and results are available from laboratory and larger scale trials. The results from these trials show clearly that low temperatures (below 85°F) will not have an adverse effect on fermentation, and in many cases may lead to a more vigorous lactic-acid fermentation than when the silage is made at higher temperatures (11, 19, 20, 31, 36, 53). There is also some evidence that there is a lower loss of nutrients at low temperatures (19).

The initial temperature rise in silage is largely an index of the degree of plant respiration which is taking place. Aerobic respiration is basically a process involving the oxidation of sugar, the end products being carbon dioxide, water and heat. When low temperatures in the mass are recorded it can be assumed that aerobic respiration has been inhibited, with a consequent reduction in the quantity of sugar used in this process. In small pilot silos, however, low temperatures may only reflect the lack of adequate insulation. It seems, therefore, that when a crop is deficient in sugar, the reduction in the amount of sugar used in plant respiration could lead to a better fermentation, and there is some evidence to support this hypothesis (31, 46).

Silage additives

It has been shown on many occasions that stage of growth will have a marked effect on the feeding value of grass and of the silage made from it (23, 49). While young grass has a high feeding value in terms of both protein and energy, it is more difficult to make into a satisfactory silage than when it is more mature, mainly because it has a high moisture and low sugar content. For the same reason the legumes do not ensile easily and, generally, some treatment is necessary when young grass or crops with a high proportion of legumes are ensiled.

A large number of treatments are available and many claims are made as to their effectiveness. One treatment—pre-wilting the crop—has already been mentioned; the other

treatments can be divided broadly into two categories:

(1) Additives which stimulate fermentation,

(2) Additives which have an inhibitory effect on bacterial growth.

The efficiency of all additives depends on their being intimately mixed with the herbage being ensiled (51). Mechanical distribution, e.g. on a forage harvester, is an ideal method of applying an additive, and solid additives, particularly those with low rates of application, are much more efficient when applied by this method. Even when fairly high volumes of an additive are used, e.g. molasses, hand application is generally much less effective than mechanical application (51). It appears, therefore, that unless a farmer takes considerable care in applying an additive by hand, the results will be disappointing.

Additives which stimulate fermentation

The traditional additive in this category is molasses. This has been tested in a very large number of trials, and there is little doubt that the addition of molasses will ensure a satisfactory fermentation, provided that an adequate quantity is evenly distributed through the herbage.

Several other materials rich in carbohydrate have been tried with varying success, one of the most interesting being cereal meal. Apart from any effect on fermentation, this additive can be useful in increasing the energy value of the finished silage, and will produce a more balanced food when added to high-protein grass or legume silage. Little advantage, in terms of a high lactic-acid content in the silage, was found with this additive until an enzyme, in the form of malt, was added to the cereal meal, resulting in a breakdown of the starch present in the cereal to sugar (37). Another additive similar in action to cereal meal is dried beet pulp, which will have a marked effect on silage fermentation, reduce seepage from the silage and increase the energy content of the silage (32). The mode of action of this additive is complex, as the effect on silage fermentation is partly due to the absorbtive capacity of the beet pulp and partly to the sugar present in it.

Additives which inhibit fermentation

Many types of acid have been used as silage additives, based on the theory that direct acidification of the mass is a more certain method of preservation than relying on bacterial fermentation. Good results have been obtained with several acids (4) and, where suitable equipment and silos are available, the addition of an acid can be a useful technique. Under our conditions, however, the type of silo in general use is not of a design where it is easy to apply acids to the herbage being ensiled, and handling the acids, particularly in concentrated form, is unpleasant or dangerous. Moreover, it is not easy to estimate the quantity of acid which should be added; over-application will result in an excess of acid being present in the silage, and this excess will have to be neutralized before the silage is fed. Generally acids or acid salts will not enhance the feeding value of silage, whereas the carbohydrate additives will increase the energy content either in the form of residual sugar or of acids derived from the sugar.

Because of the difficulty involved in handling acids, there has been considerable interest in acid salts or acids in solid form, which are easier to handle. One of these additives is sodium metabisulphite and there is a good deal of information on its use (2, 3, 6, 22, 29). It can be very efficient as an additive, but it is subject to oxidation when oxygen is present in the mass and, being soluble, it is liable to seepage losses. Kylage (a calcium formate/sodium nitrite preparation) can also give good results (1, 16), and another additive of this type which shows some promise is sulphamic acid (7). Various other acid salts have been tried with varying success (4). One of the main problems associated with all solid additives is that relatively small quantities have to be added, and it is extremely difficult to ensure intimate mixing of the additive and the herbage. This difficulty may account for the variable results obtained when these additives have been used, and it would appear

that the only satisfactory method of application is by an applicator on a forage harvester.

Antibiotics have also been used as additives, but there is little precise information on their efficiency. Chlortetracycline and bacitracin appear to be the most effective (12, 54), but more experimental work is required before the value of antibiotics can be assessed with any certainty.

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SELF-FEEDING OF SILAGE

EXPERIENCE AT THE ABERDEEN UNIVERSITY FARMS, TILLYCORTHIE, UDNY

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Self-feeding of silage has been successfully practised at Tillycorthie for 5 years. With unrestricted access to the feeding face, daily grazing times for 9-cwt. animals varied from 4 periods totalling 121 minutes in the case of stronger animals to 7 periods totalling 378 minutes.

In feeding, chopped silage was more wasteful than long silage. The daily intake of 7-cwt. animals was 68 lb. of silage and 4 lb. of oat straw. The labour requirement for 70 animals was 6·6 hours per week.

Food and labour costs on the system were 10*s.* 11*d.* per week. The estimated cost of the same items on turnips and straw feeding is 16*s.* 4*d.* per week.

The health of the cattle was good and growth excellent, and the animals went out to graze in a condition which allowed them to make maximum liveweight gain on grass.

Self-feeding of silage has been successfully practised at the Aberdeen University Farms during the last five winters.

About seventy Friesian heifers around 15 months old (6–7¾ cwt.) have been housed in a covered yard 100 ft. by 30 ft. and they winter-grazed in an adjoining roofed silo 120 ft. by 24 ft. Straw is fed in the covered yard. The floor of the silo is concreted and gates of 2 in. iron tube with bars 1 ft. 9 in. and 3 ft. 6 in. from ground level are kept in position at the face.

The animals have access to the silage throughout the 24 hours and 4 in. of feeding face is allowed per beast. In a previous winter, 24 hours observation of 9-cwt. animals indicated a daily feeding time at the face varying from 4 grazing periods totalling 121 minutes to 7 periods totalling 378 minutes. The animals' condition and general aggressiveness seemed to determine the time spent in grazing.

BUILDING COSTS

A similar set-up for 75 cattle giving 35 sq. ft. of lying room per animal with a further area for exercise might at current prices involve the following expenditure:

Silo	£1500 or net of grant	£1250
Building	£2025 or net of grant (⅓)	£1350
	£3525 or net of grant	£2600

The building grant is allowed for under the Farm Improvement Scheme. The rate of grant is "one third of actual cost" of the work or the prescribed "standard cost" for specified types of work. In this case the area of the building is 2700 sq. ft. and the "standard cost" is taken at 15*s.* per sq. ft. An initial taxation allowance of 15% is available under the heading of "Capital Expenditure on Farm Buildings" and the remainder can be written off at 10% a year until exhausted.

Annual use-costs (interest 8%; straight line depreciation over 20 years; repairs, £50 per annum; insurance and rates, £20 per annum, and allowing for present subsidy and taxation reliefs) would be about £300 per annum, or £4 per head of cattle accommodated.

At Tillycorthie, the covered yard is used for housing pigs when it is not occupied by cattle, but no credit is deducted in the above calculation of use-costs.

The silo wall

While on the subject of buildings, another useful observation may be made on silo walls. Filling has now (May 1961) been completed for the 6th year and the juice of the grass is coming through the 9 in. reinforced concrete block wall to an alarming extent. Whatever the end result, it is to be hoped that the structure and, in particular, the reinforcing will not be

permanently dam ged. There is an indication, however, that as concrete walls get older there is a danger that grass juice will penetrate further and further and this is bound to be detrimental to the structure. Routine treatment of the inside of walls with protective materials may, therefore, be advisable and it has already been suggested by Dr. Moore of the Chemistry Department, North of Scotland College of Agriculture, that a chlorinated rubber paint may be suitable. In our case, corrosion has undoubtedly occurred and a new facing of several inches of concrete would seem to be necessary.

1960–1 EXPERIENCE

Before 1960, "long" silage was provided for the cattle but in 1960–1 the crop was secured by forage harvester. Observation indicates that when silage is chopped there is slightly more waste on the "floor" on our system of feeding.

Silage available

The clamp in 1960 measured 100 ft. × 24 ft. × 6 ft., = 14,400 cu. ft., which at 46 cu. ft. to the ton = 313 tons approx. Daily consumption per head was 68 lb., or at 22% D.M. (10·4% C.P.) was 15 lb. D.M./day.

Livestock carry

77 head from 23 Nov. 1960 to 17 Jan. 1961
$55 \times 77 = 4235$ cattle-days
65 head from 17 Jan. 1961 to 20 April 1961
$93 \times 65 = 6045$ cattle-days
Total 10280 cattle-days

Spring calvers were removed on 17 Jan. 1961. Four Friesian bullocks were included for observation purposes.

Straw (fodder)

6 bales used per day., 888 bales in all, which at 3 bales/cwt. equals 14 tons 16 cwt. Assuming a small fodder contribution from the very limited bedding supplied, straw consumption would be about 4 lb./day.

Dry-matter intake

From silage	15 lb. a day
From straw say,	4 lb. a day
Total	19 lb. a day

The heifer weights ranged from 6–7¾ cwt., and 19 lb. D.M. would be about their theoretical daily intake.

Bedding

Of necessity bedding straw has been kept to the minimum, only 6 tons plus a few loads of used straw being put down during the whole winter period. At times the system is very messy, the floor of the silo being cleaned once only during the whole feeding period. These conditions seem to have little effect on animal performance so long as a reasonably dry bed is provided.

In 1960–1 there was no case of foot rot, but odd cases have occurred in previous years. In spite of the fact that the bulling heifers are at a vulnerable stage as far as teeth are concerned, no animal had to be removed during the past winter on account of "loss of condition". In previous years, withdrawals for all complaints averaged 2%.

Labour

Including any mucking done, but not carting straw to the site, the total hours of labour employed from 23 Nov. 1960 to 20 April 1961 were 138 i.e. 6·6 hours per week. Cost ¾*d.* per beast per day.

Food and labour costs

Silage 68 lb. at 2/– per cwt. (cost of production)	14½*d.* per day
Straw 4 lb. at 8/– per cwt. (purchase price)	3½*d.* per day
Labour	¾*d.* per day
	18¾*d.* per day

This equals 10*s.* 11*d.* per week, or for 21 weeks £11 9*s.* 3*d.*

Straw is a costly item and its use might be criticized. Silage is, however, a laxative food and from the point of view of animal health and the general condition of both the yard and silo, the feeding of straw is justified. Assuming that the self-feed ration with straw is providing 7–8 lb. of S.E. per day, an equivalent traditional ration in north-east Scotland might be: 60 lb. swedes (at 35/– per ton), 8 lb. straw and 6 lb. hay.

The cost of this ration works out at 25*d.* per day and for half a cattleman's time the labour charge of £5 per week would be equivalent to a daily labour cost per head of 3*d.*, i.e. four times greater. Thus on the traditional system the total daily cost might be 28*d.* and the total weekly cost at 16*s.* 5*d.* The saving is undoubtedly worthwhile.

The condition of the cattle

The cattle were taken out of the silo on 20 April 1961. Their general condition was good and growth was very satisfactory. In past years concentrates have been fed at the rate of 2 lb. per day to similar cattle. This feed was omitted during the past winter without any apparent detrimental effect. It had been our intention to weigh the cattle "in and out" but the outbreak of foot and mouth disease ruled out that possibility.

Application to beef cattle

The inclusion of 4 Friesian bullocks indicated that this system is suited to wintering cattle for grass fattening. Good growth was again observed without any undesirable increase in condition. The system has produced very thrifty animals for grass—the kind one would like to purchase but which are very difficult to find at cattle markets.

ACKNOWLEDGEMENT

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STUDIES ON THE ROOT DEVELOPMENT OF HERBAGE PLANTS

V. Seasonal changes in fructosan and soluble-sugar contents of cocksfoot herbage, stubble and roots under two cutting treatments

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Two cutting treatments were applied to a cocksfoot sward, and the changes in fructosan and soluble-sugar contents of the roots, stubble and herbage were studied over a complete year.

Both the soluble-sugar and fructosan contents of roots were at a low level throughout the experiment. The total soluble carbohydrate in the roots never exceeded 4%. It is concluded that cocksfoot roots are not important storage regions for soluble carbohydrates.

The total soluble carbohydrate in herbage varied with season and reached a maximum of 10%. It was not affected by cutting treatment.

In stubble the total soluble-carbohydrate content fluctuated markedly with season and reached a maximum of 18% in October; it was generally higher on the infrequently-cut swards than on those cut frequently. The soluble-sugar content was small and changed little with season or cutting treatment; the fructosan content, however, varied from 2 to 16·6% and accounted for most of the changes in the soluble-carbohydrate content. Stubble is apparently the major storage region for soluble carbohydrates in cocksfoot.

Under sward conditions, the quantity of soluble carbohydrates in the stubble of cocksfoot may have a positive effect on the herbage growth immediately after winter defoliation. However, when swards are actively growing in spring, other factors, such as tiller size and number, may be equally important in determining the amount of herbage recovery growth.

INTRODUCTION

The possible role of soluble carbohydrates as food reserves in grasses, and the influence of defoliation in reducing these reserves, with subsequent effects on regrowth and vigour of the plant, have been reviewed by Weinmann (10) and Troughton (7). Their general conclusions were that soluble carbohydrates may be stored as reserves in the underground organs of grasses.

Therefore, as part of a study of seasonal changes in the root and stubble weights of grasses (Baker and Garwood, 3), it was decided to make a detailed parallel investigation of the variations in the soluble-sugar and fructosan contents of an established cocksfoot (*Dactylis glomerata*) sward under two cutting treatments.

EXPERIMENTAL TECHNIQUES

A four-year-old pure sward of S143 cocksfoot was used in this experiment. Applications of 35 lb. of nitrogen per acre were made on 14 April, 12 May, 12 June, 6 August 1954 and 15 March 1955. 41 lb. of P_2O_5 and 67 lb. of K_2O were applied on 14 April 1954. There were two cutting treatments:

A. Cut every four weeks from 18 March to 22 November 1954.

B. Cut 18 March, 10 May, 5 August (after seed had set) and 22 November 1954.

Details of the layout, methods of cutting and field sampling are given in Part IV of this series (Baker and Garwood, 3).

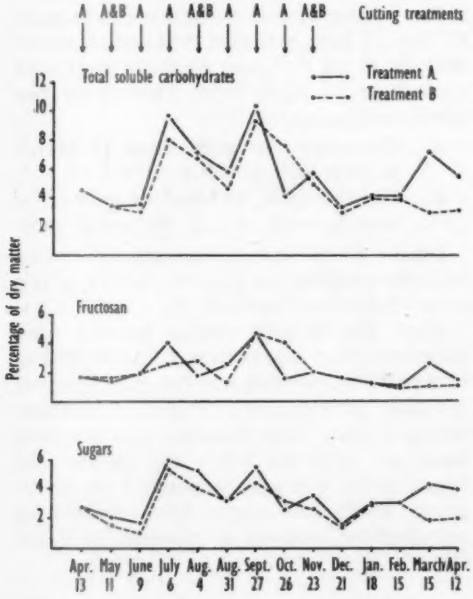
Root, stubble and herbage samples were taken every four weeks from 12 April 1954 to 12 April 1955. Stubble was the plant material left above ground after cutting off the herbage with a Tarpen hedge-trimmer, plus the stem bases and rhizomes below the surface (the height of cut was approximately 1 in. above ground level). The samples were prepared for carbohydrate analyses as reported by Baker (1).

The soluble sugars and fructosan were estimated separately. First the colouring matter in the samples was extracted in dry ether. Soluble sugars (predominantly sucrose, fructose and glucose) were then extracted in 90% alcohol. Finally the fructosan was hydrolysed and extracted from the residual material by boiling in water for 2 hours. The quantities of carbohydrates in both the soluble sugar and fructosan extracts were estimated as free hexoses by the anthrone technique described by Fairbairn (4). The total soluble-carbohydrate content is the sum of the soluble-sugar and fructosan contents.

RESULTS

Herbage

The cutting treatments had little effect on the total soluble-carbohydrate content of the herbage (Fig. 1). It decreased slightly from April to June, then increased sharply to a peak of 7·8 to 9·6% in early July. There was a second peak at the end of September, followed by a steady decline to midwinter. The percentage contents of sugars and fructosan in the herbage were similar.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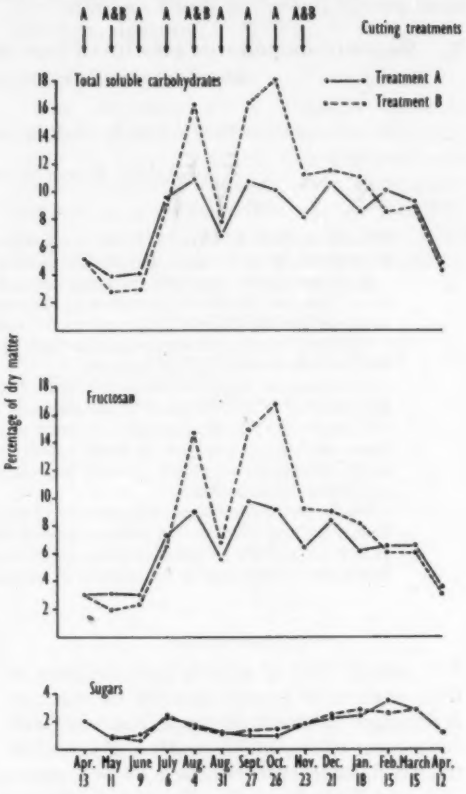
Cutting treatments
Total soluble carbohydrates
Treatment A
Treatment B
Fructosan
Sugars
Percentage of dry matter
Apr. May June July Aug. Aug. Sept. Oct. Nov. Dec. Jan. Feb. March Apr.
13 11 9 6 4 31 27 26 23 21 18 15 15 12

Fig. 1. Herbage—soluble carbohydrates.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Cutting treatments
Total soluble carbohydrates
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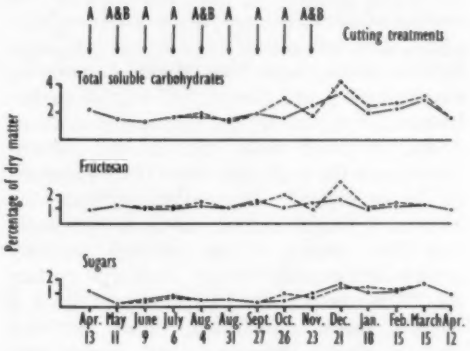
Treatment B
Fructosan
Sugars
Percentage of dry matter
Apr. May June July Aug. Aug. Sept. Oct. Nov. Dec. Jan. Feb. March Apr.
13 11 9 6 4 31 27 26 23 21 18 15 15 12

Fig. 2. Stubble—soluble carbohydrates.

Stubble

Fig. 2 shows the carbohydrate contents of the stubble. The total soluble carbohydrate in the stubble was always higher than in the herbage. This was particularly marked on the infrequently-cut swards and on both treatments during autumn and winter. The sugar content of the stubble was low throughout and varied from 0·7 to 3·5% of the dry weight. It was not affected by cutting. On the other hand the percentage of fructosan ranged from 1·9 to 16·6% according to season and cutting treatment. From April to June the fructosan content was fairly constant, but it increased sharply in both treatments to a peak at the

beginning of August, decreased during August and then rose to another peak in early autumn. There was a decrease in fructosan during autumn, winter and early spring. From August to January there was more fructosan in the stubble of the infrequently-cut swards than in the frequently-cut. The highest fructosan contents were 16·6% on the infrequently-cut and 9·8% on the frequently-cut swards. Because fructosan was the predominant soluble carbohydrate, its pattern of variation was similar to that of the total soluble carbohydrates.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Cutting treatments
Total soluble carbohydrates
Fructosan
Sugars
Percentage of dry matter
Apr. May June July Aug. Aug. Sept. Oct. Nov. Dec. Jan. Feb. March Apr.
13 11 9 6 4 31 27 26 23 21 18 15 15 12

Fig. 3. Roots—soluble carbohydrates.

Roots

Fig. 3 indicates that both sugars and fructosan were present only in small quantities in the roots. There were only small changes with season and there were no major effects from the cutting treatments. The highest content for total soluble carbohydrates in the roots was 4·1% in December on the infrequently-cut sward.

DISCUSSION

It has frequently been stated that, during periods of uninterrupted growth, grasses build up supplies of soluble carbohydrate in their roots, and that following defoliation these "reserves" are translocated above ground and utilized in the formation of new herbage (Troughton, 7). Sullivan and Sprague (5) showed that, after partial defoliation of perennial ryegrass, the soluble-carbohydrate concentration in the roots decreased markedly for 11 days, but after 28 days had returned to the original level. In the current experiment there was no evidence that cutting reduced the percentage of soluble carbohydrates in the roots. As the subsequent samples for chemical analyses were not taken until one month after cutting, the percentage could have declined and then increased during this period to the original level. However, both the concentration and weight of soluble carbohydrates per unit area (see Baker and Garwood, 3) in the roots were so low in comparison with the stubble (and moreover seasonal fluctuations were so small) that the roots of cocksfoot do not appear to be storage organs of plant food reserves.

The large concentration of fructosan in the stubble and the associated lower levels of sugars suggest that it may be the region where food reserves are stored. Moreover it was only in the stubble that cutting treatments produced large differences in the soluble-carbohydrate content, especially when the plants on the infrequently-cut treatment had made 2 or 3 months' uninterrupted growth. Reference to the stubble weights (3) shows that before being cut on 4 August, 383 lb. per acre of total soluble carbohydrates had accumulated in the stubble of treatment B compared with 259 lb. on treatment A. On 27 September, 27 October and 23 November the quantities were 594, 739 and 536 lb. per acre of total soluble carbohydrates on B and 254, 243 and 216 lb. on A.

The stubble fraction consisted largely of stem and leaf bases and it has been found that the stems of grasses tend to have higher carbohydrate concentrations, especially of fructosan, than the leaves (Waite and Boyd, 8; Tilley, 6). Moreover the region of principal photosynthetic activity, the leaf, contains less fructosan than sugars. In this experiment cutting treatments did not create different leaf/stem ratios in the stubble samples. Therefore the differences in soluble-carbohydrate contents between treatments did not appear

to be caused by different proportions of leaf and stem in the stubble samples.

On both swards flowers emerged at the beginning of June. On treatment A there was no more flowering after cutting on 9 June. Waite (9) found that in S143 cocksfoot the soluble-carbohydrate content of the herbage increased until flower initiation and then decreased until ear emergence. In the current experiment on treatment B there was a rapid increase in the soluble-carbohydrate content of the herbage during June; this corresponded with stem elongation and flower emergence. During this period there was also a rise in the fructosan content of the stubble. Presumably soluble carbohydrates were translocated from herbage to the leaf and stem bases, where they accumulated as fructosan. The reasons for the sharp drop in soluble-carbohydrate content in the stubble during August are not clear, although there was virually no green leaf left after cutting at the beginning of August, so that the subsequent recovery growth may have been at the expense of the fructosan in the stubble. On the infrequently-cut swards there was another sharp fall in fructosan content in November. Fig. 4 shows the weights of herbage on the swards at different sampling dates. On the infrequently-cut treatment the weight of herbage decreased during November. This loss was due to leaves dying and rotting; consequently there was also a reduction in the amount of green leaf available for photosynthesis. The marked fall in total soluble-carbohydrate content of the stubble from 15 March to 12 April 1955, was associated with a small increase in herbage yield (Fig. 4).

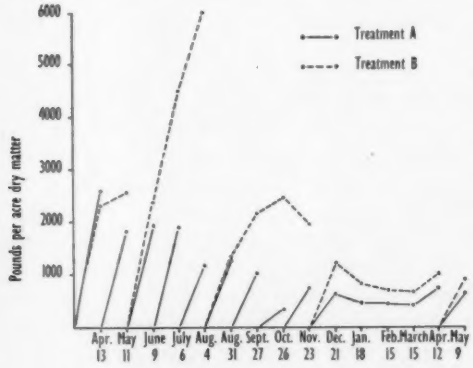

Fig. 4. Herbage yields.

The growth of herbage immediately after defoliation was always greater on the infrequently-cut plots, particularly in winter and spring (Fig. 4). During the spring, this recovery growth was not positively correlated with either the percentage or quantity of soluble carbohydrates present in the stubble before cutting. In another experiment Baker (2) found no direct correlation between the soluble-carbohydrate content of cocksfoot stubble in late autumn and herbage growth in the following spring. In both experiments the resting of cocksfoot tended to produce large tillers, and subsequent recovery growth after defoliation may have been affected not only by concentration and quantity of soluble carbohydrates, but also by the size and number of tillers, dormant buds, etc. In the current experiment the only time when there appeared to be a distinct relationship between the amount of soluble carbohydrates in the stubble and the rapidity of the herbage recovery growth was in early winter. Thus after cutting on 23 November the swards rested from 4 August made significantly more recovery growth during December than swards previously cut every month. Plants on the frequently-cut treatment had developed a prostrate growth habit, and after cutting in November still retained a large amount of green leaf. Conversely, on the infrequently-cut swards the tillers were erect and no green leaf was left after cutting, so that the initial regrowth must have drawn on stored soluble carbohydrates. As indicated earlier, the major regions where these carbohydrates appear to accumulate in cocksfoot is in the stubble. There was little change in the concentration of fructosan in the stubble on the infrequently-cut swards as this regrowth occurred. This regrowth was accompanied by a sharp fall in the weight of stubble (Baker and Garwood, 3) and hence in the quantity of carbohydrates per unit area.

It appears therefore that in the dormant season the recovery growth of cocksfoot immediately after defoliation may be related

to the level of carbohydrate reserves in the stubble. However, during periods of active growth other factors induced by previous treatments, such as size and numbers of tillers, are probably as important as the percentage of soluble carbohydrates in determining the rapidity of herbage growth after defoliation.

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EARLY BITE ON WELSH FARMS

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The practice of 'early bite' was surveyed on sixty dairy farms in Wales during the period 1958–60. Assessment in a financial sense was made of the pros and cons of this practice. It was obvious that 'early bite' was wasted or misused on many farms.

INTRODUCTION

Much has been written about the value of extending the grazing as a means of reducing production costs, particularly on the dairy farm. A paper by Thomas (1) refers to the benefit of early bite on the dairy farm, provided it brings about a saving in home-produced and bought feed. There is no refuting this argument, since *in situ* grazing has an obvious economic advantage over the indoor feeding of conserved grass and concentrates (2). The provision of such grazing, particularly during the early months of the year, means not only the saving of feed but consequential savings which accompany a change-over from a winter-housing management of dairy herds.

The deliberations of the Caine Committee (3) posed many problems concerning the utilization of grass, with particular reference to the low returns which are still obtained despite the technical advances made in grass production. The report emphasized the need to encourage farmers to record feed inputs on their farms and to rationalize their use in the light of the potential output of their grassland. With this in mind it was decided to investigate the practice of 'early bite' on farms in the Principality—this being the technique whereby leys, particularly those based on Italian ryegrass, can by management give grazing at least fourteen days before other grassland is available for grazing.

Earlier assessments have suggested dry-matter yields of around 6 cwt./acre available for 'early bite' (4), while more recently Baker *et al.* (5) have quoted figures of the order of 10 cwt. or more. In terms of financial saving, Runcie (6) quotes £1 per week per cow for a fortnight of earlier grazing, showing a total saving of £80 for a 40-cow herd. Undoubtedly 'early bite' during March–April shows a remarkable potential for milk production, provided it is allowed to express itself. This survey, conducted during 1958–60, was intended to provide some estimate of the contribution made by early grass on dairy farms.

THE SURVEY

Records were kept on eighteen farms in 1958, nineteen in 1959 and twenty-three in 1960. These farms were distributed throughout Wales, the choice being restricted to those which had an acreage of ley managed for 'early bite'.

The majority of leys recorded fall into the pure Italian ryegrass group, the remainder being leys containing a high proportion of this grass with early perennial ryegrass varieties.

The period of 'early bite' was taken as the number of grazing days available to the dairy herd before other grass, not managed for early bite, was ready for grazing. Data were collected for (1) the daily quantities of hand-fed food and (2) the output of milk per day.

These were available for a seven-day period prior to turning out and during the period of 'early bite'.

Account was taken of the money spent on nitrogenous fertilizer as a spring dressing to produce the early grass. No account was taken of other fertilizers applied or of the proportional costs of ley establishment, neither was any credit given to the 'early bite' period for any change in labour or other costs arising from the change-over from indoor feeding.

It was assumed that the pre-grazing ration would have continued had grass not been available for grazing. The costs of feeding stuffs were based on current prices while milk was charged at the appropriate pool price.

Period of early bite

There were obvious seasonal effects, largely governed by weather, which influenced the beginning of grazing from 'early bite'. During the three years under review, 1960 proved to be the earliest season and 1958 the latest; on average there was around 10 days difference when farms in the same locality were compared.

The 'early bite period' taken for evaluation covered a wide range when individual farms were compared; this difference was not obvious in the average for the three years.

TABLE 1. Period of 'early bite'

	Early bite began (Dates range for all farms)	Early bite lasted (days) Average	Range
1958	3 March — 29 April	20	10–28
1959	1 March — 21 April	21	8–37
1960	28 Feb. — 14 April	24	10–35

The quality of the leys and their management influenced their earliness and these factors had more effect than the weather conditions in any season. This revealed itself when farms in the same area on similar soil types were compared, giving differences of the order of 7 days in earliness.

The survey did not allow an appraisal of other grassland on the farm; its condition could certainly have influenced the period taken as 'early bite'. At the same time the date of turning out was reflected in the milk prices prevailing at the time and influenced the eventual value placed on early bite.

Nitrogenous fertilizer

Over the 60 farms an average of 47 units of nitrogen per acre were applied in early spring as a preparation for 'early bite'. The amounts applied appeared adequate, though exceptionally there was a luxury use.

The following table gives the average input of nitrogen fertilizer for the three years with the range for all farms.

TABLE 2. Application of nitrogen as units/acre (cwt. fertilizer × % N)

	Average	Range
1958	50	18– 68
1959	48	18– 74
1960	44	23–109

There was considerable variation in the time of application relative to date of commencing grazing. On average the fertilizer was applied a month before, and the following table shows the range for 48 of the farms included in the survey.

TABLE 3. Time of nitrogenous fertilizer application

Days before turning out	No. of farms
<14	4
14–28	13
28–42	17
>42	14

On some farms nitrogen fertilizer was being applied too early in the season to get reasonable benefit from it, whilst on others it had been left too late.

Feed balance

The level of hand-feeding during the 'early bite' period showed a range of levels between farms both on a quantitative and qualitative basis. In some instances there was little or no saving in feed, and more often this was not countered by any appreciable increase in milk yield. Where there was a feed saving, this varied between an emphasis on bought-concentrate saving or an emphasis on bulk-feed saving. The following shows a grouping of all farms.

TABLE 4. Distribution of farms showing form of main feed-saving

	Bulk feed (Hay, silage, roots)	Concentrates
1958	15	3
1959	8	11
1960	11	12

After 1958 there was a tendency to move toward a greater saving of concentrates in addition to bulk feeds.

These differences in feeding stuffs saved were reflected in the financial figures for all materials fed, as the following table shows:

TABLE 5. Saving in feeding stuffs per acre of early bite

	Average	Range
1958	£13 12 4	£5 2 11 to £32 5 5
1959	£14 10 0	£1 1 8 to £38 14 10
1960	£10 14 5	£1 12 3 to £29 9 10

Milk revenue

There was an element of increased revenue from milk sales for all except six of the farms; these six farms showed a reduced revenue during the 'early bite' period. The increased revenue was partly influenced by the introduction of fresh calvers, either immediately before or during the period of early bite, but, as the bias in these herds was towards autumn calving, the increased yields were, in the main, a genuine reflection of the stimulating effect of 'early bite'. It was of interest to note that two of the herds which showed a decreased milk yield on early bite had previously been grazing on kale.

As has been shown earlier the date of turning out had some influence on the milk revenue for any one farm, owing to the differential pool prices during the March–April period.

TABLE 6. Extra milk revenue per acre of early bite

	Average	Range
1958	£4 12 4	−£0 4 8 to £12 1 1
1959	£4 12 4	−£0 17 4 to £12 6 5
1960	£5 18 5	−£2 3 6 to £19 5 5

Financial saving from 'early bite'

After considering the saving in feed together with the increased revenue from milk and debiting the money spent on nitrogenous fertilizer, the following table gives the position on these farms for the three years.

TABLE 7. Saving per acre of early bite

	Average	Range
1958	£16 6 9	£5 15 4 to £43 0 9
1959	£17 8 11	£1 2 1 to £43 1 5
1960	£16 15 3	£3 5 6 to £34 15 1

A further analysis of these returns shows the distribution for all farms.

TABLE 8. Distribution of savings

Saving/acre	No. of farms	Average/acre
>£20	20	£28 2 9
£10–£20	23	£14 0 10
<£10	17	£6 12 10

The influence of feed saving and increased milk revenue has already been shown but the influence of stocking rate must not be forgotten in its obvious influence on the returns per acre. A consideration of the farms on this basis shows the variation encountered; more often too large an acreage had been set aside for 'early bite', with a consequent poor utilization during the period when grass was expensive, but worthwhile if properly used.

TABLE 9. Influence of stocking rate on return per acre

Cows/acre early bite	Average return/acre	No. of farms
5·5	£19 16 4	40
2·8	£11 0 6	20

DISCUSSION

The main conclusion of this survey concerns the success or otherwise of the farmer in exploiting the feed potential of early grass. Where there was a financial advantage to the farmer in providing early grazing this was mainly due to a feed saving, whether of bulk feed or bought concentrates. The survey did not aim to consider the question of concentrates *versus* bulk feed but it was clear that a considerable saving in expenditure was possible with both.

The confidence which these farmers had in early bite was reflected in the pattern of feeding during this period. Over the three years it was shown that at least 21 days' full-time grazing was possible before other grass was available. During this 21-day period, the first 7–10 days was regarded as the change-over phase in the feeding ration, and in most instances this involved a cutting down in the quantities of food fed. As the period of grazing increased,

until the dairy herd was out-of-doors night and day, the majority of farms showed a considerable decline in the bulk foods fed, but the concentrates picture was not so consistent. In some instances the concentrate level was maintained, while some showed a change in the type fed, with a greater emphasis on starchy supplements. Where all feeds were drastically reduced, this in most cases was accompanied by an increased milk output, and it was obvious that the potential of early bite was being realized. It is certain that in too many instances the rationing of hand-feeds was unrealistic and not consistent with food derived from the early bite.

There are a number of direct measures of assessing grassland output which have been used on farms; these include cow-equivalent grazing days and utilized output of starch equivalent (7). All have their protagonists but it is generally agreed there is, as yet, no single criterion acceptable to all. So often the values credited to grassland are the residues following the deduction of theoretical values for other feeds. No attempt has been made in this survey to evaluate the utilized feed values of the 'early bite' period, misleading as this would be, neither has there been an attempt to place an absolute financial value on early bite. The main consideration was to demonstrate in the simplest possible way what happened in practice when early bite was available. The survey certainly revealed that the proper use of early grass can lead to a considerable saving of money on dairy farms, but that many farmers tend to undervalue its potential contribution to milk production. Some farms wasted the resource of 'early bite' by feeding heavily with concentrates when grazing alone could be expected to contribute a major share, if not the whole, of the production requirement.

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ADVANCE NOTES ON RESEARCH

THE EFFECT OF NITROGEN FERTILIZER ON THE WATER-SOLUBLE CARBOHYDRATE CONTENT OF PERENNIAL RYEGRASS AND COCKSFOOT

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INTRODUCTION

Increasing attention is being given by plant breeders and agronomists to the soluble-carbohydrate content of herbage, while at the same time more use is being made of nitrogenous fertilizers in practical grassland husbandry. These fertilizers are known to increase the yield and nitrogen content of grass, but there appears to be little published information on their effect on soluble-carbohydrate content.

Waite (11) has shown that increasing the amount of compound fertilizer in combination with frequent cutting result in herbage low in soluble carbohydrate but high in protein. In water-culture studies, Vose (10) and Alberda (1) have shown that frequent defoliation and increasing nitrogen levels lead to a decrease in soluble carbohydrate in perennial ryegrass. Steger and Puschel (9) found that increasing fertilizer-nitrogen levels reduce the sugar content of a grass sward up to the hay stage. These results may be of direct significance in the nutrition of the ruminant under systems of grassland management involving the intensive use of nitrogenous fertilizers. The significance may be in relation to the rumen metabolism of protein (2) and of non-protein nitrogen compounds (8) or in the relative proportions of volatile fatty acids produced in the rumen (4).

EXPERIMENTAL

Work is in progress at the Welsh Plant Breeding Station on the effect of the intensive use of different nitrogenous fertilizers on the yield and chemical composition of pure grass swards. The effects of some of these treatments on total-soluble-carbohydrate content are briefly reported in this note. The results refer to two field experiments laid down in 1959, the first to study primary growth (Exp. 1) and the second to study successive re-growth throughout the season (Exp. 2). First harvest year data are presented for S23 ryegrass and S143 cocksfoot which received nitrate of soda as the nitrogenous fertilizer.

Samples for chemical analysis were taken with sheep shears in both experiments. The herbage was dried for 4 hours at 80°C in a Unitherm oven, milled and stored for analysis. Such drying has been shown to result in small changes in the soluble carbohydrates of grasses (7). In the present study, however, the treatment effects found were of such a magnitude as to render small differences unimportant. Total soluble carbohydrate was determined on a hot-water extract of the material by the anthrone method of Yemm and Willis (13) using the reagent described by Deriaz (3).

Experiment 1. Primary growth

Samples of primary growth were taken for yield determination and chemical analysis at intervals from 5 April to 13 June. The two treatments were no nitrogen, and nitrate of soda applied at the rate of 80 lb. N/acre one month before each sampling date. All plots received a basal dressing of phosphate and potash in March 1960.

Table 1 shows that nitrate of soda increased dry-matter yields, total nitrogen and nitrate nitrogen, compared with the control.

Water-soluble carbohydrate at each sampling date is lower in the nitrogen treatment for both grasses, and lower in cocksfoot

TABLE 1. The effect of nitrate of soda on dry-matter yield, percentage crude protein, and nitrate N during primary growth

		S23 perennial ryegrass			S143 cocksfoot		
		5 April	17 May	13 June	5 April	17 May	13 June
D.M. yield*	−N	1000	3000	3900	700	1800	3300
(lb./acre)	+N	1400	3800	5500	900	3100	4400
Crude protein	−N	18	8	6	20	10	6
(per cent)	+N	27	15	10	32	19	11
Nitrate N	−N	Trace	Trace	Trace	Trace	Trace	Trace
(per cent)	+N	0·12	Trace	0·03	0·32	0·08	0·04
Soluble carbohydrates	−N	17·5	24·3	22·3	5·7	12·3	7·3
(per cent)	+N	7·5	12·0	11·7	2·7	6·1	3·7

*Samples cut with sheep shears

than in ryegrass, as shown also by Waite and Boyd (12) and work at the Grassland Research Institute (4).

Experiment 2. Regrowth

The first cut was made on 13 April, and thereafter the regrowth was cut at intervals of 4 weeks up to the end of September. The fertilizer treatments were as in Exp. 1, the nitrate of soda being applied one month before each cut.

Fig. 1 shows that the water-soluble-carbohydrate content of both grasses was markedly depressed in plots receiving nitrate of soda; the effect was greatest in the spring and autumn. The seasonal pattern was similar with and without nitrogen, and there was a peak in mid-season. Ryegrass again showed a consistently higher carbohydrate content than cocksfoot.

As in Experiment 1 the nitrate of soda increased the yield of dry matter, total nitrogen and nitrate nitrogen at each cut (Table 2).

The pattern of seasonal change in soluble-carbohydrate content is the inverse of that for total and nitrate nitrogen. Thus spring and autumn cuts produced herbage high in protein and low in soluble carbohydrate.

DISCUSSION

Waite (11) concluded that the application of fertilizers combined with frequent defoliation gave a rapid growth of leafy material which would be expected to be low in soluble carbohydrates and high in protein. In Waite's work the frequency of defoliation increased with the level of fertilizer application and it is not therefore possible to dissociate the two effects. The present results show that under the same cutting management, dressings of nitrate of soda markedly depressed the soluble carbohydrate in primary growths and re-growths of

TABLE 2. The effect of nitrate of soda on dry-matter yield, percentage crude protein, nitrate N in spring, summer and autumn regrowth cuts

		S23 perennial ryegrass Cuts			S143 cocksfoot Cuts		
		First 13 April	Fourth 7 July	Seventh 29 Sept.	First 13 April	Fourth 7 July	Seventh 29 Sept.
D.M. yield*	−N	435	295	110	140	500	95
(lb./acre)	+N	1250	2100	600	750	1300	250
Crude protein	−N	19	11	15	20	12	20
(per cent)	+N	27	17	25	32	20	31
Nitrate N	−N	Trace	Trace	Trace	Trace	Trace	Trace
(per cent)	+N	0·15	0·05	0·35	0·30	0·09	0·59
Soluble carbohydrates	−N	15·2	19·1	10·7	8·1	12·9	6·8
(per cent)	+N	6·7	17·9	7·2	4·7	8·3	4·4

*Samples cut with autoscythe

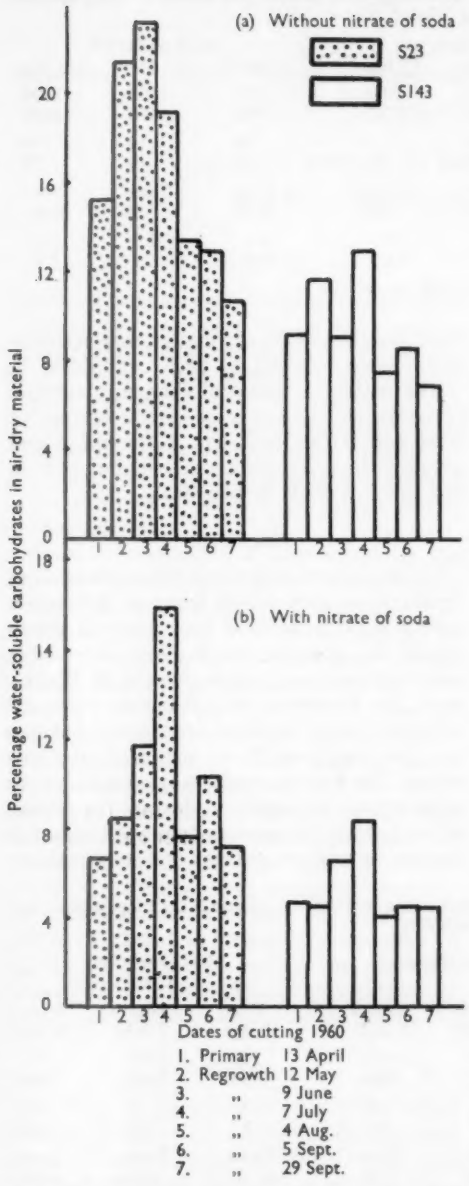

Fig. 1. The effect of nitrate of soda on soluble-carbohydrate content of monthly regrowth cuts.

ryegrass and cocksfoot. Work at this Station with other grasses and other forms of nitrogen supports the data given here on the effects of nitrate of soda on ryegrass and cocksfoot. For example, urea, while giving a far lower yield of dry matter than nitrate of soda, nevertheless produces a similar depression in soluble carbohydrates, so that it would seem that soluble-carbohydrate content is not simply related to rate of growth.

It has been suggested (4) that the soluble-carbohydrate content of herbage is related to volatile-fatty-acid production in the rumen. The depression of soluble carbohydrates by nitrogen fertilizers may thus be of direct significance in the use the ruminant is able to make of its food. As already mentioned, it may be significant in relation to nitrogen metabolism. Since the application of nitrogen results in grass of low soluble carbohydrate and high protein, the question arises whether the animal is in fact able efficiently to utilize these high-protein diets. Recent work by Hickey (5) has shown high crude protein in grass to be associated with an increased rate of thermogenesis in dairy cattle, leading to a lowered feed efficiency. High nitrogen fertilizing of swards and the feeding of energy supplements to cattle have both been mentioned as factors concerned with the incidence of hypomagnesaemia (6); it may be well, therefore, to note the effect of nitrogen on soluble carbohydrates in this connection. In relation to non-protein nitrogen compounds, such as nitrate, the present work has shown that high nitrate contents usually occur when soluble carbohydrates are low—conditions which would be expected to favour nitrate poisoning in the animal (8).

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A FILTRATION PROCEDURE FOR THE *IN VITRO* DETERMINATION OF DIGESTIBILITY OF HERBAGE

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Tilley *et al.* (1) have clearly demonstrated that their rumen liquor and pepsin procedure for the determination of digestibility of herbage is useful and precise. The method has, however, the disadvantage that the equipment required for the centrifugation stages is relatively expensive and, moreover, when using one centrifuge only the procedure is somewhat tedious. The method outlined below completely eliminates centrifugation; the rumen-liquor stage is terminated by acidification and the residues from the pepsin stage is recovered by filtration, using a filter aid. Digestible dry matter or digestible organic matter may be determined; results for the former estimation on thirteen samples already examined at Hurley have given satisfactory results.

METHOD

Digestion is carried out in Pyrex 32×200 mm. boiling tubes. The tubes are fitted with special caps which make possible the introduction of acid by means of a hypodermic syringe and needle. At the end of the rumen-liquor stage two 2 ml. portions of 1+4 HCl are added to each tube and the pH of their contents adjusted to pH 1·2. An interval is allowed between the two additions of acid to permit any froth to settle. Injection through the cap has the advantage that once the needle is withdrawn any tendency of the froth to rise in the tube is restricted. Residues at the end of the pepsin stage are recovered by filtration in the presence of 1 g. of pre-ignited Hyflo supercel. In these conditions rapid filtration under vacuum is possible through a tared and pre-ignited 5·5 cm. fibre-glass filter-paper, for which a special funnel has been designed. Each tube requires about 40 seconds to filter, and five washings pass through immediately. The weight of the residue is determined by drying for 48 hours; in calculating the results allowance is made for the residue from the control tubes and for the 1 g. of filter aid which was added.

RESULTS AND DISCUSSION

Experiments have shown that recovery of the filter aid is virtually complete and that pre-ignition of the filter aid and paper at 500°C does not affect the recovery. The use of a filter aid and fibre-glass paper capable of withstanding ignition at this temperature means that it should be possible to determine the organic matter in the residues by the change in weight on igniting the dried residues.

Thirteen samples for which the *in vivo* digestibilities were known were kindly offered by J. M. A. Tilley for examination. Determination of the digestible-dry-matter content on

these samples by this method gave a co-efficient of correlation of r=+0·97 with the *in vivo* figures. The regression equation Y=0·84 X +15·76 (standard error of estimate ±2·34) was calculated, where Y=*in vivo* digestibility and X=*in vitro* digestibility. The standard error between duplicate estimates by the method was found to be ±0·64. Although giving lower levels for *in vitro* digestibility than Tilley's method, the two methods correlate well, as shown by the correlation co-efficient of r=+0·97.

It is thought that this approach to the problem of residue recovery in *in vitro* digestibility estimates is helpful because the procedure is simple and less expensive equipment is required. Full details of the method are available from the authors.

ACKNOWLEDGEMENT

Thanks are due to K. L. Blaxter of the Hannah Dairy Research Institute, Kirkhill, Ayr, for supplies of rumen liquor.

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CHROMOSOMES AND GRASS BREEDING

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The plant breeder is always searching for new material possessing desirable characteristics for developing into improved varieties. With increasing emphasis on extending the grazing season towards winter growth this search has been intensified, particularly in regions of high elevation in centres bordering on the Mediterranean.

Thanks to active collaboration with F.A.O., and as a result of specific expeditions from this country, promising breeding material has already been collected, and in some instances developed into potential varieties. For example, a diploid cocksfoot collected from Mount Sintra, near Lisbon, has been developed at Aberystwyth into a variety which produces at least twice the winter growth of the normal tetraploid varieties, and continues to grow satisfactorily at other times of the year (3).

Considerable interest has also been shown in tall fescue from North Africa, but potential varieties so far developed, although producing good out-of-season growth, are less satisfactory during the normal grazing season. In our opinion the indigenous forms of tall fescue, as exemplified by the established variety S170 and the best varieties of Italian ryegrass, fulfil the purpose better for present farming systems.

Another approach for the future is to breed a variety which incorporates the good agronomic qualities of both Italian ryegrass and tall fescue. This is more difficult than straightforward selection breeding because Italian ryegrass is a diploid with 14 chromosomes, and tall fescue is normally a hexaploid with 42 chromosomes. The direct cross with 28 chromosomes is sterile, but by artificially doubling the chromosome number my colleague Elfed Lewis has successfully produced fertile hybrid lines between S22 Italian ryegrass and S170 tall fescue.

More recent work with a view to combining Italian ryegrass with the North African tall fescue has revealed an interesting cytological picture for further breeding. A collection of tall fescue (F.A.O. No. 3437) from the High Atlas mountains at an elevation of 5000 ft. is shown to be different from the normal forms in

having 70 chromosomes*. These plants with such a hybrid number are chromosomally unstable, with consequent variation in seed fertility, as shown by the following data derived by Elfed Lewis and my colleagues in the Cytology Department.

Plant No.	Chromosome No. (2n=)	Percentage seed set (open-pollination)
1	70	57·9
2	70	81·2
3	70/72	11·7
4	70	56·2
5	70	72·9
6	70	38·3
7	70	91·8
8	71	75·2
9	70	63·6
10	70	48·8
11	70	55·1
12	70	33·2
13	70	82·6
14	70	76·9
15	70	85·2
16	70	76·9
17	70	52·9
18	69	No inflorescences produced
19	70	51·0
20	70	67·0
21	70	40·6
22	68	65·2
23	70	51·9
24	—	35·0
25	70	70·0
26	70	57·5
27	—	67·5
28	70	37·5
29	70	46·1
30	70	59·6

There are differences between plants in the behaviour of the chromosomes at pollen-grain formation, and it will be seen that despite the unusual chromosome number some of the plants are highly seed fertile. Further breeding involving selection for stable lines should, therefore, result in enhanced seed potential and more uniformity in agronomic characteristics.

But perhaps of greater significance for future breeding is the possibility that chromosomally different forms of tall fescue will offer greater opportunity for producing successful fertile hybrids with Italian ryegrass. The work of Saint-Yves (2) at the beginning of this century, and later of Levitsky and Kuzmina (1) show that these forms exist abundantly in North Africa. Further collections from this area should, therefore, prove very profitable towards meeting the needs of the plant breeder.

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(*Received for publication 31 August 1961*)

*The material examined was provided by the Grassland Research Institute, Hurley, labelled G.R.I. No. Bs 361 = P.B.I. Syn. 2 late.

A LABORATORY APPARATUS FOR FREEZE-DRYING HERBAGE SAMPLES

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A laboratory apparatus has been constructed which makes use of a commercial compressor-type refrigeration unit and enables fresh or previously-frozen herbage samples to be freeze-dried in trays. During drying the moisture content and temperature of the herbage have been determined and shown to be closely related.

INTRODUCTION

In studies of the chemical composition of herbage plants, the method of preparation of the plant material for analysis is of fundamental importance. Many of the chemical constituents of the plant undergo rapid change after harvesting and the changes will continue until all enzyme action has been stopped. Labile compounds may be destroyed, not only by enzyme action but also by methods used to dehydrate the plant.

Methods employed for the preparation of herbage samples have been reviewed by Davies *et al.* (5), and by Bathurst and Allison (4), who concluded that the freeze-drying method was less likely to cause damage to unstable constituents of herbage than either heat-drying or the use of boiling alcohol. Davies *et al.* (5) described equipment suitable for drying up to 500 g. of herbage using a mixture of 'Drikold' and acetone in the condenser. The limitations of heat-drying and alcohol extraction soon became apparent when a detailed investigation of the structural carbohydrates of herbage was begun (2). It became necessary to freeze-dry a large number of herbage samples for analysis, and the high cost of 'Drikold' as a refrigerant made the simple but efficient apparatus of Davies *et al.* too expensive to run. Accordingly, an apparatus has been constructed which makes use of a commercial compressor-type refrigeration unit and enables the fresh or previously-frozen herbage samples to be freeze-dried in trays.

THE APPARATUS

The apparatus (Plate 1) consists of four main parts:

1. *Main drying chamber*

The body of a secondhand horizontal-type hospital autoclave of internal dimensions 36-in. length, 20-in. diameter, is used as the drying chamber (a). The quick-release door mechanism provides easy access to the chamber and the door seal was found to be effective for use under vacuum. Four equally-spaced shelves of 16 s.w.g. copper sheet and 30 in. long are fixed within the chamber so that there is a gap of about 3 in. between the ends of each of the shelves and the end of the chamber. The shelves provide accommodation for thirty aluminium trays each $10 \times 5{\cdot}75 \times 1{\cdot}75$ in. A continuous system of $\frac{1}{2}$ in. copper piping, through which heating water is circulated, is soldered to the bottoms of the shelves.

A hole of 12-in. diameter is cut through the centre bottom of the chamber and a $\frac{1}{8}$-in.-thick steel collar with $\frac{1}{2}$-in.-thick flange is welded in. Bolted to this flange is the cylindrical chamber (b) which houses the evaporator of the refrigeration system. The evaporator chamber has internal dimensions of 12-in. diameter and 15-in. depth and is closed at its bottom end by a flat steel plate 0·5 in. thick. The flanges at each end of the chamber are fitted with O-ring seals to ensure vacuum tightness.

2. *Refrigeration system*

Within the evaporator chamber, mounted on the bottom plate, are the refrigerator expansion valve and the evaporator coil which consists of 25 ft. of 0·5-in. tinned copper refrigerator tubing wound into a helical coil. Beneath the chamber is the compressor and

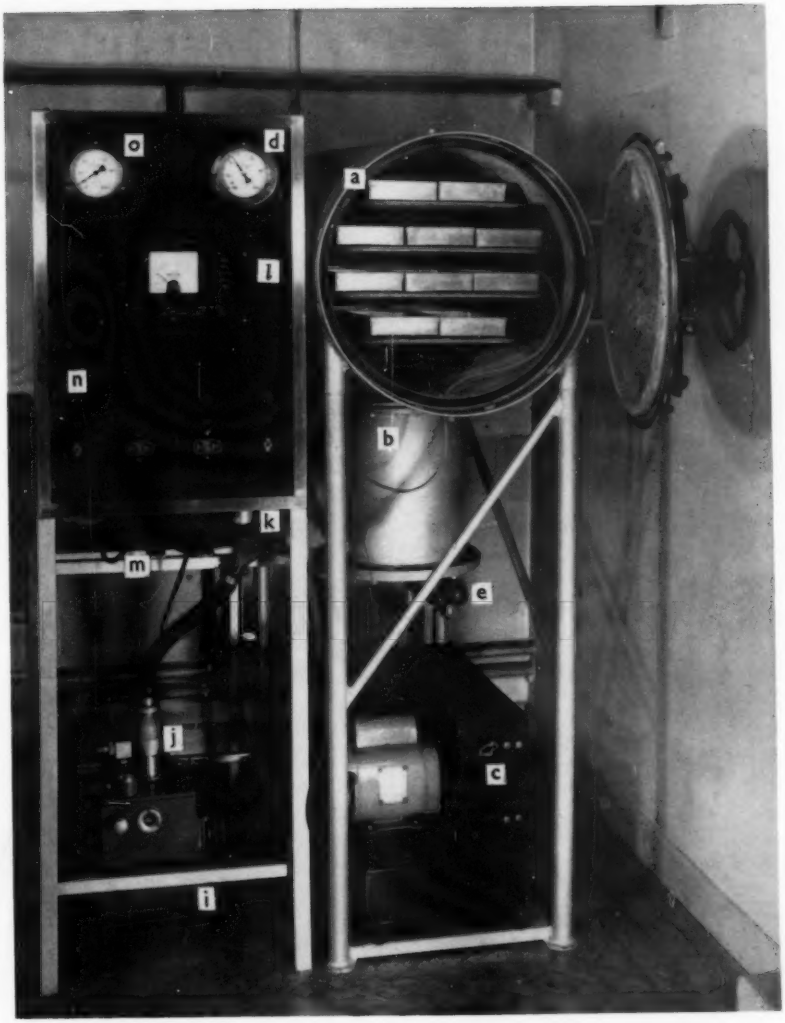

Plate 1. Laboratory apparatus for freeze-drying herbage.

To face page 278

condensing unit (c) which is capable of extracting 200 B.t.u. per hour with an evaporator temperature of about −50°C, using Freon 12 refrigerant. A dial thermometer (d) on the control panel is used to indicate the evaporator coil temperature, the bulb being clamped to the coil and the capillary coming out through the bottom plate of (b) via a vacuum-tight seal. Also fitted to the bottom plate of the evaporator chamber is the diaphragm valve (e) which is used to admit air to the drying chamber when it is required to release the vacuum at the end of a run. The valve also forms part of the water defrosting system shown in Fig. 1. To defrost the evaporator coil the diaphragm valve (e) is

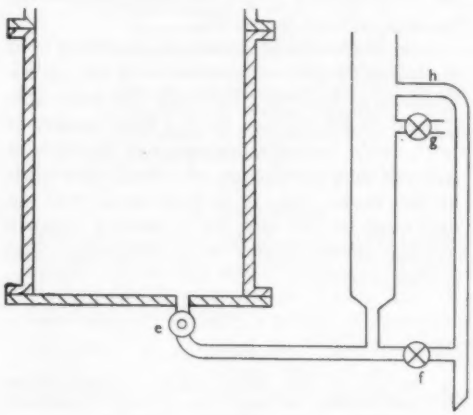

Fig. 1. Water defrosting system.

opened, the stopcock (f) closed and hot water is admitted at (g). The water covers the coil in the evaporator chamber and the level rises to that of the overflow tube (h). When de-frosting is complete the system may be drained by opening the stopcock (f).

3. *Vacuum system*

The air-ballasted vacuum pump (i), having a free air displacement of about 144 litres per minute and an ultimate vacuum of about 0·005 mm. of mercury, is suspended on springs to reduce the transmission of vibration. A non-return valve (j) prevents the pump oil being sucked out into the general system if there should be a power failure while the chamber is under vacuum. Connection to the drying chamber is by 0·75-in. bore rubber vacuum tubing to a metal pipe in the side of the chamber (b). Water vapour is thereby drawn from the drying chamber over the refrigerator coil. The vacuum level is indicated by means of the Pirani type gauge (k) with its associated controls and meter (l) mounted on the main control panel.

4. *Heating system*

Some form of heat must be supplied to the material being dried to provide the latent heat of evaporation of the water content. A centrifugal pump (m) circulates water from a 2-cubic foot capacity bath (n) at the rate of about 400 gallons per hour through the copper piping soldered to the shelves in the drying chamber. The water is heated in the bath by a 1 kw. electric immersion heater controlled by a thermostat so that the temperature may be set to any desired value. Actual water temperature is indicated on the dial thermometer (o).

DRYING PROCEDURE

With the drying chamber and the air valve (e) closed, the refrigerator is switched on and when the temperature reaches −50°C, the herbage samples are lightly packed into the aluminium trays, at about 100 g. per tray, and the trays are placed on the shelves in the drying chamber. The drying chamber is immediately closed and the vacuum pump switched on to run on partial air ballast. Within a few minutes, when the vacuum has reached about 1 mm. of mercury, the water circulating pump is switched on. After 30 minutes, the vacuum will have reached about 0·5 mm. and will continue to fall until the highest vacuum obtainable under these conditions is reached at about 0·3 mm. of mercury. After about 6–8 hours the bulk of the water content will have been removed and the air-ballast can be shut off, enabling a vacuum of 0·10–0·03 mm. of mercury to be maintained for final drying.

RESULTS AND DISCUSSION

A thermocouple laid in one of the trays was used to follow the actual temperature of the herbage samples during drying. A typical curve relating sample temperature to drying time is shown in Fig. 2.

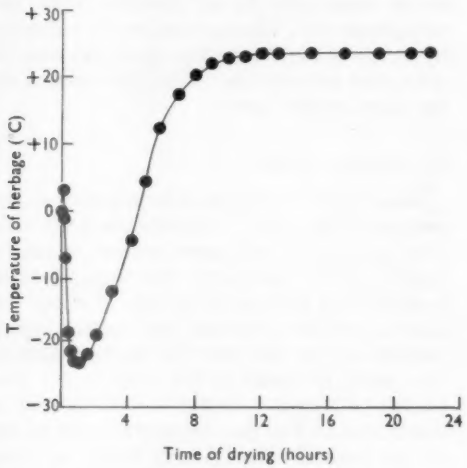

Fig. 2. Temperature of herbage during drying.

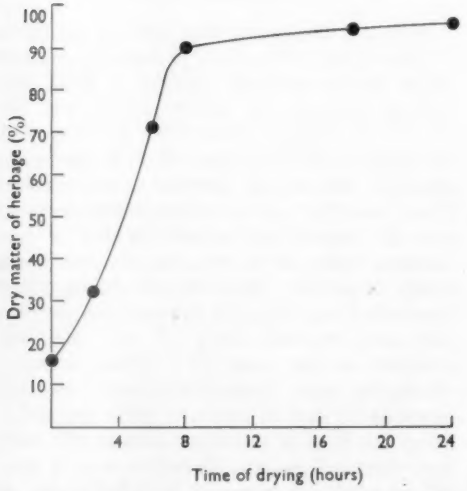

Fig. 3. Dry matter of herbage after drying for various times.

In other experiments, the rate of drying was measured by removing samples of material from the drying chamber at intervals and determining their moisture content by drying at 100°C. The results are presented in Fig. 3, it will be seen that during drying the percentage dry matter is closely related to the actual temperature of the material as indicated in Fig. 2.

It was also found that, in the later stages of drying, heat generated by the water pump raised the temperature of the circulating water above ambient temperature. To prevent excessive heating of the herbage, therefore, water, at about 20°C, is circulated only during the first 5 hours of drying. It will be seen from Fig. 2 that this corresponds approximately to the period during which the temperature of the herbage remains below 0°C.

This freeze-drying procedure has been used in studies of the nutritive value of the carbohydrates of various grasses for the dairy cow (1) and of the evaluation of a large variety of cattle feeds, including grasses and legumes, in terms of their production of volatile fatty acids in the rumen (3). It is considered that an apparatus of this type has a definite place in detailed investigations of green herbage and similar materials.

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THE EFFECT OF WHITE CLOVER AND NITROGENOUS FERTILIZER ON THE PRODUCTION OF A SWARD

I. TOTAL ANNUAL PRODUCTION

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Three-year leys of cocksfoot/white clover and cocksfoot alone were dressed with 0, 35, 105 and 210 lb. N per acre every year to provide information on the effect of clover and N on annual production.

White clover contributed 40% of the dry-matter yield but its presence was responsible for 77% of this yield where no N was used: it was responsible for less than 8%, and contributed 5%, where 210 lb. N per acre was applied annually. It was estimated that grass alone receiving 160 lb. N per acre would yield as much dry matter as a mixed sward receiving none.

Clover had the indirect effect of raising yield of nitrogen in the companion grass by 60 lb. per acre per year. A maximum of 106 lb. was recorded in 1958.

The response of the mixed sward averaged 10 lb. of dry matter per lb. N. Prevailing economic circumstances will determine if this level is satisfactory in practice.

The recovery of N by grass alone varied from 54% at the lowest level of N to 80% at the highest. On mixed swards apparent recovery was negative or low: N was to a large extent only replacing the effect of clover which was suppressed by its use.

Factors influencing response and the difference between that obtained under experimental and practical conditions are discussed.

The use of N to produce out-of-season grass may give good response, but may cause a reduction in clover contribution.

INTRODUCTION

White clover has represented a very important source of nitrogen in the sward but within the present century there has been an ever-increasing availability and use of nitrogenous fertilizer.* It is useful to review the role of white clover against this background.

A number of authors have reported experiments in which white clover has been evaluated, and there are innumerable publications dealing with the effects of N on swards which need not be quoted here. The fact is that N almost always increases the dry-matter yield of a sward and that this increase is accompanied by a decrease in the yield of the white clover, either immediately or after a short time. In this country most of the evidence presented has been obtained from cut swards. Some data have been obtained where the influence of the animal has been included (20), and Tayler and Rudman (16) discussed experiments where animal output at various levels of N was measured.

The question of the relative importance of white clover and fertilizer nitrogen has been discussed by Davies and Williams (6). They suggested that N should be used as a means of increasing production from a grass/clover sward, the yield of which has been largely determined by the relative amount of clover to grass and by the management. The question was also examined by Walker *et al.* (19) who attempted to characterize mathematically the various contributions to yield of nitrogen. The results of Wilman (21) do not agree well with the findings of Walker *et al.* but represent a further contribution to our understanding of the problem.

This study was designed as a sequel to that carried out at Stratford-on-Avon in 1951 (5). The chief modification in technique was to use

*Throughout this paper, N represents nitrogen in nitrogenous fertilizer.

three-year leys which were subjected to particular treatments throughout their life instead of for distinct short periods within a year. The application of fertilizer in alternate periods allowed residual effects to be partly measured and thus preserved some of the advantages of the discontinuous system. Cocksfoot was used as a companion grass, which is of interest because white clover has generally done less well with this species than with others (12).

The object of this paper is to examine total annual yield with particular reference to the relationship between N and white clover.

METHOD

Two sowings were made at Hurley, (in August 1955 and April 1956), each providing four replicates of an experiment in which different seeds mixtures were treated with various levels of N. Individual replicates were split to allow N to be applied in two different seasonal patterns and in each of these divisions there was a plot of each of the three seeds mixtures:

(a)	Cocksfoot, S37	15 lb. per acre
(b)	Cocksfoot, S37	15 ,, ,,
	White clover, S100	5 ,, ,,
(c)	Cocksfoot, S37	5 ,, ,,
	White clover, S100	5 ,, ,,

(Data from (c) are not included in this paper).

These plots were divided further and the sub-plots (15 ft. × 10 ft. 6 in.) received 0, 35, 105 or 210 lb. N per acre annually in two equal dressings. The fertilizer used was nitro-chalk (15·5% N). (For simplicity of presentation its N content has been approximated to 17·5 lb. per cwt.) The dressings were applied before the first and third cuts in one series of plots, and before the second and fourth in the other.

The dates of cut were the same for all plots and were adjusted to give a cut at the early silage stage, followed by three cuts timed to give similar production to each other. A fifth cut was taken late in the season if necessary, but no additional N was applied.

The plots received an annual dressing of phosphate and potash in spring, giving 54 lb. P_2O_5 and 120 lb. K_2O per acre. Additional potash (120 lb. K_2O per acre) was given after the second cut in each year except 1957 when, following a heavier spring dressing, half the quantity was applied.

Both sowings were on a sandy loam of alluvial origin with a pH in water between 6·0 and 6·8. The soil was low in organic matter and had a total nitrogen content of 0·13% (in top 6 in.)

A sample, made up of two one-yard-wide strips cut through the length of each sub-plot, was used to estimate yield. The content of dry matter and the botanical composition were determined from sub-samples taken from each sub-plot. The cutting height of the auto-scythe used was about 2 inches.

Determinations of nitrogen content were carried out on the dry matter sub-samples and on the botanical separates from each plot. For this purpose the clover fractions from replicate plots were bulked.

Weather conditions

Summaries of meteorological data for Hurley appear in the Annual Reports of the Institute (7). Briefly, a dry summer in 1955 was followed by a very hard winter. In 1956 and 1957 dry spring and early summer months were followed by wet conditions. The year 1958 was very wet and lack of moisture was unlikely to have limited growth. In contrast, 1959 was one of the driest years for a long time and growth of grass was seriously limited because of this, particularly in early summer and autumn.

RESULTS

The yields of dry matter for each harvest year of each sowing are represented in Fig. 1. The data for the mixed grass/clover sward are from the higher grass-seed rate only. (The pattern of production from the two mixtures with clover was fairly similar and will be examined in a subsequent part of this article.) A mean of the two series (time of application of N) has been used, because, except in 1959, there was little difference between them in total production. The distribution within the season was, of course, changed.

Dry-matter yield

In Fig. 1 the total yield, and the yield of the grass component of the mixture, are shown for

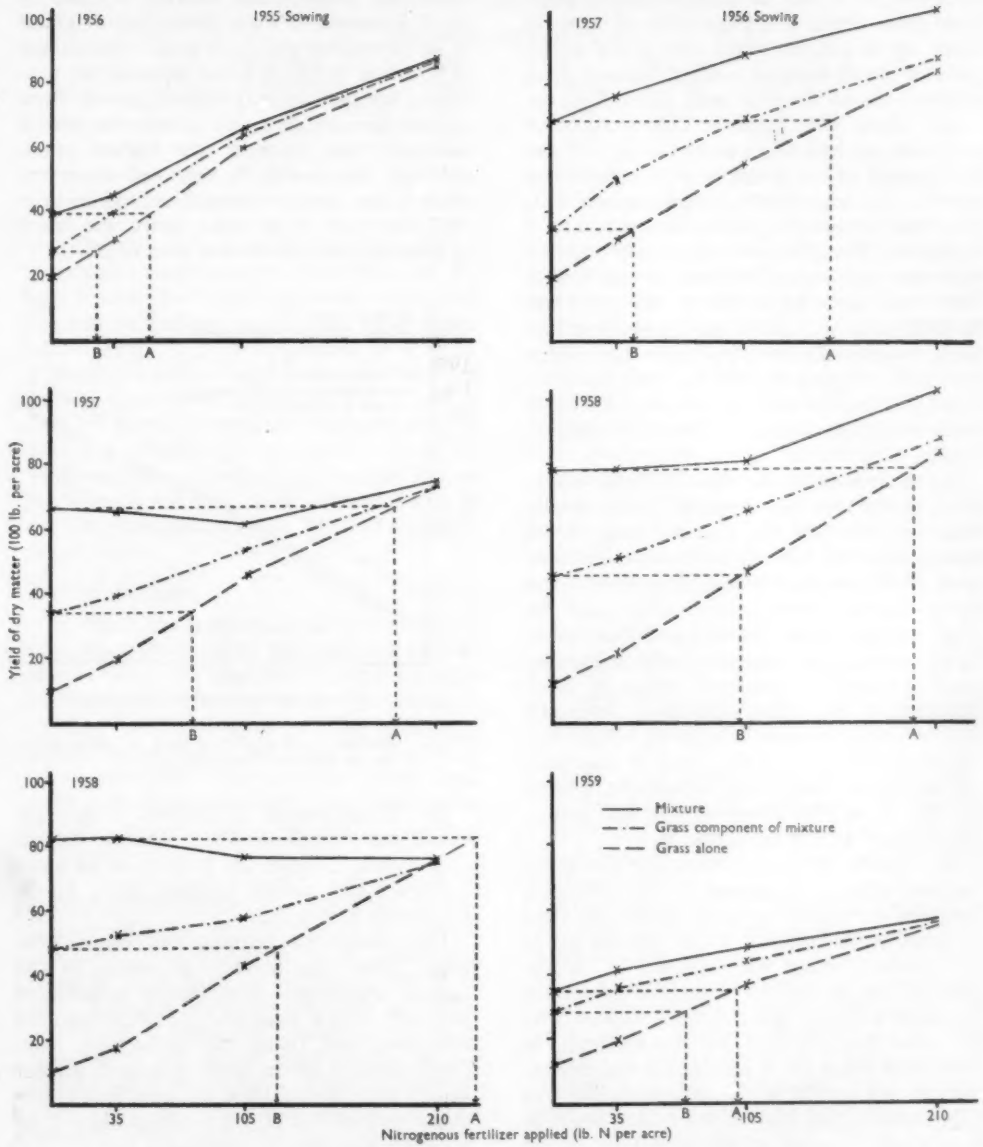

Fig. 1. Total annual yield of dry matter under different N treatments
A. Gross effect of clover equivalent
B. Indirect effect of clover equivalent.

each level of N and are compared with yield from grass alone. The gross effect of clover is made up of a direct effect, that is the actual yield of clover herbage, and an indirect effect which it has on the grass with which it grows.

(*a*) *Gross effect of clover.* The gross effect of clover on yield where no N was applied can be equated to the quantity of N required to produce a similar yield from grass alone. This has been indicated by interpolation in Fig. 1 (point A). The effect is seen to vary with the year and was highest in 1958. It was low in 1956 when clover development was poor; but in 1959, although clover gave a lower actual yield, its gross effect was equivalent to a higher level of N on grass. In 1957 and 1958 the effect was higher on the older sward (*cf* ≡ 180 lb. N with ≡ 155 lb. N, and ≡ 230 lb. N with ≡ 220 lb. N.)

An assessment of the value of clover where N is applied may also be made. It can be seen that the yield of the mixture was, in all instances, above that of grass alone at the same level of N. In the earlier sowing the yields from the two swards were very similar under the highest N treatment. Clover established slowly in this sowing, and was never able to increase once the high N treatment began in 1956. Although in the later sowing clover developed well before the treatments were applied in 1957, the clover content declined once N was used. At the highest level it had almost disappeared by the end of the experiment but had contributed more than in the earlier sowing.

(*b*) *Indirect effect of clover.* The size of the indirect effect is measured by the difference between the yield of grass alone and the yield of grass in the mixture. It was greatest where the clover content was highest, i.e. in the control. The quantity of N required to produce an equal effect on grass alone is indicated by the point B in Fig. 1. It was at a maximum in 1958, and where no N was used it was equivalent to 105 or 120 lb. N on grass alone. An indirect effect can also be clearly seen where N was applied, except at the high level in the earlier sowing.

Dry-matter response to fertilizer nitrogen

(*a*) *Grass-alone swards.* Relevant data from Fig. 1 have been brought together in Fig. 2. Response to N was almost linear—about 30 lb. dry matter per lb. N in all years except 1959, when it was reduced because the prolonged dry spell severely limited growth. Both sowings gave a higher yield in their first year of treatment than in their later harvest years, although response to N remained about the same. Under identical climate and treatment in 1957, the yield of the older sward was lower by a similar amount at each level of N.

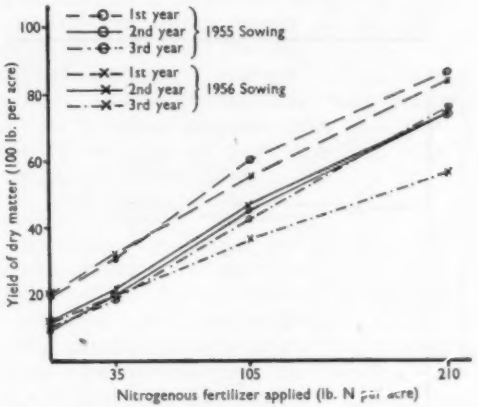

Fig. 2. Annual yield of dry matter of grass alone under different N treatments.

(*b*) *Mixed swards.* In contrast to the grass sward, the mixture showed a variable pattern of response, because the proportion of grass to clover was rapidly modified once the N treatments had begun.

Fig. 1 shows that response was good in 1956 when clover was developing slowly. In the control and low-N plots, clover contributed only 10% of the yield of dry matter from the first three cuts. In the two subsequent years (1955 sowing) clover made a large contribution in the controls: there was very little clover at the high level of N. The net response to N at all levels was poor or negative.

In the later-sown plots, the best response was again obtained in the first year of treatment. There was a very good build-up of clover in the seeding year and, although it declined

TABLE 1. Mean annual yield of two 3-year leys 1956-9

Dry matter, 100 lb. per acre

N applied lb. per acre	Grass alone	Mixture		
		Grass	Clover	Total
0	13·8	37·0	24·4	61·4
35	23·9	44·5	20·5	65·0
105	47·8	58·9	11·6	70·5
210	75·1	77·4	3·8	81·2
	±0·81	±0·80	±0·70	±0·94

with the start of treatments in 1957, it made a noticeable contribution to yield, even at the high N level. In 1958 a comparison shows that response to nitrogen was slightly better in the later sowing.

The mean annual yield shown in Table 1 is derived from all six graphs in Fig. 1 and is therefore biased towards the results obtained in 1957 and 1958 when both sowings were under treatment. The response in yield of dry matter per lb. of N was 10·3 lb., 8·7 lb. and 9·4 lb. at the low, medium and high levels of fertilizer, respectively.

Yield of nitrogen

In Fig. 3 the quantity of nitrogen harvested annually is presented in the same way as yield of dry matter. The contribution made by white clover, expressed in terms of nitrogen, exaggerates its value over that expressed as dry matter, because clover had a higher nitrogen content than grass under the cutting system used (even at the highest level of N) and because the presence of clover raised the nitrogen content of the grass associated with it.

(*a*) *Gross effect of clover.* The amount of fertilizer which would have raised the yield of nitrogen of grass alone to that of the mixture is shown in Fig. 3 at point A. It varied from about 80 lb. N per acre in 1956 to 308 lb. in 1958. Because the value of clover is greater when yield of nitrogen is considered, the slight response in dry-matter yield in the second harvest years represents a negative response when yield of nitrogen is considered. This situation is also seen when mean annual yield of dry matter (Table 1) and nitrogen (Table 2) are compared.

(*b*) *Indirect effect of clover.* The amount of fertilizer needed to produce on the companion grass an effect similar to that of white clover is shown by point B in Fig. 3. The amount varied from 32 lb. N per acre in 1956 to 144 lb. in 1958; in the last case the indirect effect was estimated as just over 100 lb. per acre of nitrogen in absolute terms, and represented 35% of the whole yield of nitrogen.

The weighted mean percentage of nitrogen of the grass alone and of the grass growing with clover was, (1) 1·81 and 2·29 in control plots, (2) 1·84 and 2·22, (3) 2·05 and 2·29, and (4) 2·56 and 2·69 at the three increasing levels of N.

The recovery of fertilizer nitrogen*

The data presented in Table 2 allow an estimate of the percentage recovery of fertilizer N.

With grass alone the recovery was 54%, 70% and 80% for the increasing levels of N. The recovery of the final increment, calculated by using data from the medium and high level of N, was 90%.

In a mixed sward, the percentage recovery of N may be based on either the whole yield or the grass fraction of the yield. In either case the values are lower than those obtained with pure grass. This is because of the differences in the gross, or in the indirect, contribution of clover —high in the control but decreasing with increasing N level. When calculated on gross yield, recovery is estimated as an apparent loss at the low and medium levels of N and as 19% at the highest level. When calculated on the yield of the grass fraction of the mixture the

*The percentage recovery of N is calculated from: $\frac{\text{Increased yield of nitrogen over control}}{\text{Amount of N applied as fertilizer}} \times 100$

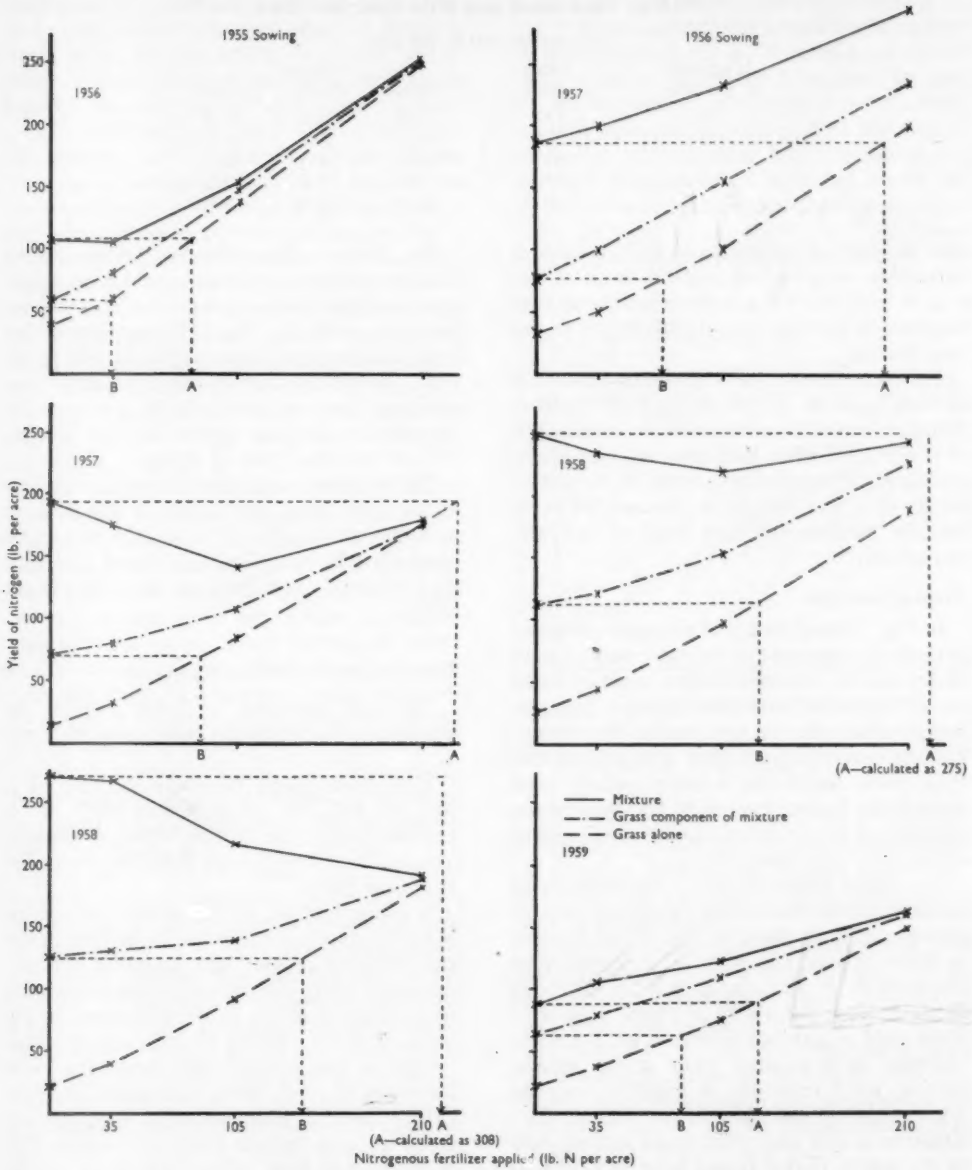

Fig. 3. Total annual yield of nitrogen under different N treatments
A. Gross effect of clover equivalent
B. Indirect effect of clover equivalent.

TABLE 2. Mean annual yield of two 3-year leys 1956-9

N applied lb. per acre	Nitrogen, lb. per acre: Grass alone	Mixture: Grass	Mixture: Clover	Total
0	25	85	98	183
35	44	99	83	182
105	98	135	47	182
210	192	208	15	223
	±2·49	±1·90	±2·78	±3·19

recovery of N was 40%, 48% and 59% for the increasing levels of N.

DISCUSSION

In the 3-year leys studied, clover was responsible, directly and indirectly, for 79% and 76% of the production of dry matter where no nitrogenous fertilizer was used. It was responsible for only 1% and 14% where the annual input of N was 210 lb. per acre. On the other hand, it is calculated that grass alone, with the annual application of about 160 lb. N per acre, would give a similar yield of dry matter to the mixed sward receiving none. This is in general agreement with results obtained elsewhere in the United Kingdom and in the U.S.A. (Table 3). It is interesting to note that the value was so high with cocksfoot, since Holmes and Maclusky (12) found that cocksfoot responds better to N and is not so compatible with white clover as are other species; the recent report by Herriott and Wells (10) supports this.

The fertilizer equivalent of the gross effect of clover varied from year to year. This was largely due to the variation in the yield of the mixture which, as has been mentioned, was dependent on the growth of clover. In 1958, when clover was very active (doubtless because of the very wet weather), grass alone would have required 228 lb. N per acre to yield as much dry matter as the mixture. In 1956, when clover contribution was low, the comparable figure was only 65 lb. N. After the first year the yield of grass alone declined; apparently an effect of age and perhaps due to a reduced rate of soil nitrification. (This suggestion is prompted by the fact that the yield of grass alone in the two sowings differed by a similar amount at each nitrogen level when compared under the same climate and treatments in 1957.) The variations in the yield of the mixture mask the fact that this decline in yield of grass alone tends to increase the fertilizer equivalent of the gross effect of clover.

The average amount of nitrogen transferred annually by clover was 60 lb. per acre, equivalent to the use of 73 lb. N per acre on grass alone. Although this is not as high as the transfer of 140 lb. of nitrogen estimated by Sears (15) in New Zealand, it does represent a useful contribution to production. In fact there was an apparent transfer of 106 lb. of nitrogen in 1958, which gave an effect on yield equivalent to that of about 120 lb. per acre fertilizer N.

TABLE 3. Amount of nitrogen required by grass alone to replace the gross effect of clover

	lb. per acre per year: Dry-matter basis	N-yield basis
Holmes & MacLusky (12)		
Average 5 years. 12 grasses	121	212
Wilman (21)		
Average 3 years. Ryegrass	184	260
Cowling & Green (5)		
Short periods. Cocksfoot	162	238
Wagner (17, 18)		
Average 2 years. Cocksfoot	160	200

In the two 3-year leys used in the present study nitrogenous fertilizer increased dry-matter production. In some years, it is true, the higher levels of N were not able fully to make up for the loss of clover occasioned by earlier dressings. A similar result was reported by Watkin (20) in a trial incorporating grazing animals. It is doubtful if it is so frequent an occurrence as to imply, as some authors have suggested (11, 20), that the use of small dressings of N may not be good farm practice. The response of mixed swards in this study, and in some reported elsewhere (3, 8, 13), seems to indicate that over 3 or more years the dry-matter response to N remains fairly constant over the levels of N which are likely to be used in practice in the immediate future.

In this study the dry-matter response was between 8·7 and 10·4 lb. per lb. N, close to the value of 10 lb. calculated from many published data by Davies and Williams (6). Castle and Holmes (3) reported a value of about 8 lb. where 520 lb. N per acre were used annually.

The best response to additional N was obtained in the first year of treatment of each sowing, although for different reasons. In the first sowing the mixed sward was very low in clover and tended to react as if it were grass alone. In the second sowing there was an indication that the benefits of both N and clover were realized together in the first year of treatment. However, the clover failed to recover and allow the process to be repeated. In subsequent years the clover-depressed swards under the high N treatments required nearly all of the N applied to bring their yield to that of the clovery control. It may be expected that the first dressing on any mixed sward will usually give a better response than will be obtained from subsequent dressings. This is because the lowering effect of clover depression on yield is not immediately realized.

Although responses in dry-matter yield were obtained from additions of N, yield of nitrogen did not follow a similar trend. Where no N was used, clover represented 40% of the yield of dry matter, and because it invariably had a higher content of nitrogen than grass, its contribution to yield of nitrogen was even greater. Additions of N increased the yield of nitrogen in the grass component but failed to compensate for the loss from the clover, except at the highest level used. Although yield of nitrogen may not be of great significance in relation to animal production, it is of consequence when considering the circulation of nitrogen in grassland systems.

It is often difficult to interpret data of the recovery of N and the present investigation serves to emphasize the value of including grass-alone swards in studies of nitrogenous fertilizers and grassland. Thus, although the apparent recovery of N on the mixed sward was "negative" at the low and medium levels of application, it was recovered very efficiently by grass alone. N was not, in fact, being lost because of unsatisfactory soil or inclement climate; the "negative" recoveries with the mixture were due to the failure of N to replace the contribution from clover.

Response to nitrogen in general

When a survey of experimental results is made with a view to estimating the response which might be obtained from the use of N on grassland many factors will affect the conclusions. The duration of individual trials, and the proportion of short-term trials (in which only a single fertilizer dressing is examined) included in the survey will influence the average response computed. Average responses will be lower from long-term than from short-term trials.

Another factor which may influence response is the amount of clover in the sward. Boyd and Lessells (2) studied results from a number of trials on frequently-cut leys and obtained an average response of 16–20 lb. dry matter per lb. N. This value lies between the response of the mixture (8–10 lb.) and grass alone (27–30 lb.) in the present experiments and may indicate that there was little clover in many of the trials they surveyed.

Some practical considerations

On the farm the control plot in the experimenter's sense does not exist. The farmer is confronted with a sward and the response from it will almost always be higher than the 10 lb. dry matter per lb. N which is commonly found experimentally. As the clover content

of a sward declines it becomes increasingly responsive to N, the effect of which is very marked. What is not usually known is how productive the sward would have been if clover had been maintained at a higher level by not using N. This is determined by the experimenter from a control plot, the yield of which forms a basis for the calculation of responses.

It is interesting to consider what response to additional N might be obtained if it should become necessary to use very large quantities of N on grassland. In the present study the grass swards responded well up to 210 lb. N per acre and the N was effectively recovered even at the high levels. Castle and Holmes (3) found the response to fertilizer after continual usage of high levels—up to 520 lb. N per acre—was still almost 8 lb. of dry matter per lb. N, but emphasized the need to ensure an adequate supply of other nutrients. Prevailing economic conditions will determine whether this level of response is sufficient to justify discounting the part which white clover might have played in production. It would seem unwise to leave clover out of the seeds mixture, even if fairly high levels of N are to be used. In the present study it made a small contribution even where 210 lb. N per acre were used each year.

Under dry conditions, irrigation improves the uptake and utilization of N. Usually it fails to improve response to N of mixed swards because it also enhances the contribution from clover in the control plots (4, 9, 14). It is perhaps not surprising that, where shortage of nitrogen limits production, white clover, which can fix nitrogen, will make a greatly increased contribution when an inadequate moisture supply is corrected.

The greatest value of N may be to produce grass early and late in the season: this has not been considered in the present study. Responses under such conditions may be low in absolute terms, although in a recent report Baker (1) found them quite high in spring. His results may have been influenced by the fact that continual yield estimates were not made and thus any depression in yield later in the season due to loss of clover was not estimated. This does not detract from the fact that in some years response to N may be high early in the season. There is then a strong chance that clover depression may also be serious. It may be wrong to assume that because clover is not growing very actively it is not likely to suffer from competition. It may in fact be vulnerable for this very reason. If the value of N dressings for producing out-of-season grass is to be accepted, then so must a reduction in the contribution from clover.

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THE EFFECT OF PHOTOPERIOD AND TEMPERATURE ON THE RELATIONSHIP BETWEEN THE ROOT AND SHOOT SYSTEMS OF *LOLIUM PERENNE*

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In controlled environment cabinets, root growth relative to shoot growth varied directly with the temperature within the range 50°–80°F. Increasing the photoperiod from 6 to 12 hours increased the root growth relative to shoot growth; additional hours of light had no further influence on this ratio. These results are discussed in relation to the maintenance of a balance between photosynthesis and the absorption of water and minerals.

INTRODUCTION

Previous experiments (10, 11) have shown that the relative growth of the roots and shoots of grasses is affected by the water and nitrogen status of the soil, the intensity of light to which the shoot is exposed, the degree of competition between the plants, and the production of flowers. This paper describes a further series of experiments in which the effects of temperature and photoperiod on the relative growth of these two parts of the plant were studied.

EXPERIMENTAL METHODS

The plants were grown from seed of *Lolium perenne* New Zealand (Nucleus stock ex Grasslands Division, D.S.I.R.) in 6-pint glazed earthenware pots filled with clean river sand, each pot containing 4 plants. The pots were watered once a day with half-strength Hoaglands solution. Immediately after sowing, the pots were placed in constant-environment cabinets; these have been described by Mitchell (7). Each cabinet held 18 pots, and the light intensity inside was approximately 4000 ft.c. When nearly all the plants had developed two tillers, three pots were removed from each cabinet and the roots of the plants washed till free from sand. The roots and tillers of each plant were counted; following this, the plants were oven-dried and weighed. This was repeated on six occasions at 2–3 day intervals.

The environment in the cabinets varied in temperature and photoperiod. Four temperatures (50°, 60°, 70° and 80°F) were used in conjunction with a rhythm of 12 hours light : 12 hours darkness. At 60°F four rhythms of photoperiod were used, namely 6 hours light : 18 hours darkness, 12 hours light : 12 hours darkness, 18 hours light : 6 hours darkness, and continuous light for 24 hours.

The relationship between the dry weights of the root and shoot systems of the plants has been described by means of the allometric formula. The reasons for using this formula have been discussed elsewhere (9); it may be written:

$$y = bx^k$$

when y represents the weight of the root
x „ „ „ „ shoot
b „ a constant equal to the weight of the root when that of the shoot is unity
k represents a constant equal to the ratio $\dfrac{\text{log. growth rate of the root}}{\text{log. growth rate of the shoot}}$

The constant k provides a convenient method of comparing the growth of the roots and shoots. Its value for each environment was calculated by the major axis method of Kermack and Haldane (4).

The growth rate of the whole plant (root plus shoot) was calculated as the regression of

*This work was carried out at the Plant Physiology Unit, Department of Scientific and Industrial Research, Palmerston North, New Zealand, while the author was on study leave from the Welsh Plant Breeding Station, Aberystwyth.

the logarithm of the mean plant weight at each harvest on the number of days after sowing. The regression of the root or shoot weight on the number of roots or shoots, i.e. the increase in weight associated with the growth of one root or one tiller, was calculated for each treatment, to form a basis of comparison of the weights of individual roots and tillers.

The plants measured in these experiments were all young, so that the difficulties associated with measuring growth taking place concurrently with decay were avoided. The seeds were not subjected to vernalization, so that changes in the relative growth of the roots and shoots caused by flowering would not occur (Fejer, 3).

RESULTS

These are presented in Table 1. Figure 1 illustrates in greater detail the results obtained for one environment.

The growth of the plant increased with successive rises in temperature from 50° to 70°F, but was retarded by a temperature over 70°F. The growth of the root relative to that of the shoot, as shown by the value of k, increased with rising temperature. The weight of an individual tiller, as indicated by the regression of the weight of the plant on the number of tillers, increased with a rise in the temperature from 50° to 60°F but was unaffected over 60°F. The weight of an individual root remained constant within the range 50° to 70°F, but increased when the temperature was raised to 80°F.

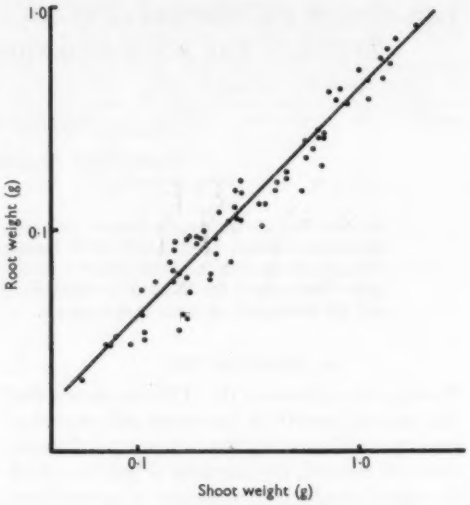

Fig. 1. Plants grown at 60°F with 12 hours photoperiod: weight (g) of root plotted against weight of shoot on a logarithmic scale.

As the photoperiod increased, so in general did the growth of the plant. This intensification of growth, however, was somewhat irregular, as the extension of the photoperiod from 12 to 18 hours had little effect upon it. The growth of the root relative to that of the shoot increased when the photoperiod was lengthened from 6 to 12 hours, but additional hours of light beyond 12 did not affect it. The weight of

TABLE 1. The growth of *Lolium perenne* as influenced by temperature and photoperiod

Temp. (°F)	Photoperiod (hours in each 24)	Growth rate (g./g./day)	k	Regression of weight (0·0001 g.) on numbers	
				Tillers	Root
		Temperature			
50	12	0·050±0·004	0·994±0·032	103± 8	18±2
60	12	0·089±0·007	1·045±0·039	173±10	21±4
70	12	0·101±0·022	1·078±0·037	158±16	19±2
80	12	0·074±0·003	1·188±0·048	182±11	28±5
		Photoperiod			
60	6	0·056±0·005	0·919±0·051	128± 2	15±1
60	12	0·089±0·007	1·045±0·039	173±10	21±4
60	18	0·093±0·004	1·029±0·035	170± 5	34±5
60	24	0·126±0·015	1·033±0·026	229±16	45±5

individual tillers and roots varied in the same manner as the photoperiod; the tillers, however, showed little response to photoperiod in the 12 to 18 hour range.

DISCUSSION

It is possible to explain the results of previous investigations on the effects of environmental changes on the relative growth of the roots and shoots of grasses, using the principle of homeostasis. To do so, it is assumed that these changes would tend to maintain a balance or steady state between the major function of the shoot (photosynthesis) and the major function of the root (the absorption of water and minerals). For example, a dry soil resulted in a relatively large root system. If the assumption is made that a given weight of root would absorb more water from a wet soil than from a dry one, then the development of a larger root system in a dry soil would tend to maintain the same balance between photosynthesis and absorption in both soils. A low soil nitrogen status has a similar effect as shortage of water, and can be explained in a similar manner. Shading increased the growth of the shoot relative to that of the root. In a shaded plant the phytosynthetic activity per weight of shoot would be low due to lack of light, compared with the absorptive activity per unit weight of roots. The production of relatively more shoot would tend to maintain the same balance between photosynthesis and absorption as would high light intensity.

The growth of both the root and shoot was increased by higher temperature and a greater intensity of light, the root more than the shoot (Troughton, 11). This may be interpreted as an increase in both photosynthesis and absorption per unit weight of root or shoot, the photosynthesis increasing more than absorption. The rate of photosynthesis in a number of experiments has been shown to increase with rising temperature, usually having a Q_{10} of 2 or more (6). A relative shortage of water or minerals with increasing temperature could therefore be caused by the processes utilizing the water, or by the minerals having a Q_{10} greater than that of photosynthesis, or the processes involved in their absorption having a Q_{10} less than that of photosynthesis.

The minerals absorbed by a plant usually enter into chemical combination with the products of photosynthesis; it would be expected therefore that the rate at which minerals were utilized would vary with the rate of photosynthesis. The relationship between photosynthesis and water is very largely indirect, in that relatively little water enters into the chemical changes associated with photosynthesis, compared with the very large amount expended in transpiration. This process is linked with the maintenance of turgidity of the leaf cells, thus keeping the stomata open and allowing an unobstructed intake of carbon dioxide (6). From the data of Bierhuzen (cited by Wassink, 12) with rye, Went (14) with tomatoes, and Brouwer and Vliet (2) with peas, transpiration would seem to have a Q_{10} of approximately 2 up to about 70°F and possibly somewhat less at higher temperatures. The process of utilization of both minerals and water would therefore seem to vary in the same manner as photosynthesis with increasing temperature. Any relative shortage of water was therefore probably due to the process of absorption having a Q_{10} of less than 2.

Absorption is a complex process, and it is not known to what extent it is biological or purely physical in action. If it was purely physical it would be expected to have a Q_{10} of between 1·2 and 1·4 (6), which would be in agreement with the conclusion suggested above.

Kramer (5) stated that the available evidence indicated that most of the water-absorption by transpiring plants occurred by passive absorption, which presumably is a purely physical process with a low Q_{10}. The Q_{10} of the absorption of minerals by a root was stated by Robertson (8) to depend upon the concentrations of ions in the solution surrounding the root, the Q_{10} being lower for concentrated than for dilute solutions. Under the conditions of this experiment, in which the plants were watered with nutrient solution, this process would therefore be expected to have a low Q_{10}. There would thus seem to be strong grounds for suggesting that the increase in the root system compared with the shoot

system associated with increasing temperature is linked with the rate of water and mineral absorption having a Q_{10} less than that of photosynthesis.

The variations in the relative growth of the root and shoot systems associated with changes in temperature can thus be explained on the same homeostatic principle as was used to explain the effects of other environmental factors. This concept of balance between absorption, translocation and photosynthesis undoubtedly over-simplifies some of the physiological processes taking place in a plant. There are other processes also governing growth in plants, and in certain situations they may be the controlling ones.

The increase in the growth of the root compared with that of the shoot when the photoperiod was extended from 6 to 12 hours can be explained by the concept of balance between photosynthesis and absorption. Stomata respond to light by opening (6); therefore with a photoperiod of 12 hours they would remain open longer than with a photoperiod of 6 hours. More water would be lost per unit weight of leaf. As far as is known the increase in photoperiod would not affect the rate of water and mineral absorption by the roots, so additional root growth would be required to supply the extra water utilized by transpiration.

The lack of response, in the relative growth of the shoot and root, to increased photoperiod beyond 12 hours may have been due to the inability of the plant to respond to this alteration in light or to some change by the plant itself which rendered further response unnecessary. In the environments for which this variety of *Lolium perenne* was bred it would experience maximum photoperiods of more than 12 hours but less than 18. The lack of response, through variations in the relative growth, to increases in the photoperiod from 12 hours to 18 and 24 hours may indicate that the plants do not possess the necessary genetic make-up to respond in this way to photoperiods longer than those naturally encountered. The irregular changes in growth rate and the size of individual roots and tillers when the photoperiod exceeded 12 hours support this view. Regular changes would have been anticipated if the plants had been well adapted to the difference between environments. A more drastic instance of the inability of certain plants to respond to a modified environment is given by Wassink and Wiersma (13), in that *Pinus* plants from northern latitudes were unable to adapt themselves to short-day conditions, resulting in abnormal growth. This was considered to be due to the loss of genes, compared with plants from southern latitudes which were able to adapt themselves to short days.

The plants also reacted to variation in the environment by changes in the size of their constructional units (roots and tillers). Photoperiod had a greater effect upon them than temperature, as the size of the roots and tillers increased with additional light. Temperature had relatively little effect upon these measurements, the size of the tiller only being affected when the temperature was increased from 50 to 60°F, and the roots when it changed from 70 to 80°F. The finding that the size of the tiller did not change over a wide range of temperature is in accordance with the results of Mitchell (7) and Alberda (1).

ACKNOWLEDGEMENTS

Acknowledgement is made to the Government of New Zealand for the award of a National Research Fellowship during the tenure of which this work was carried out. Grateful thanks are due to Dr. K. J. Mitchell for facilities and advice. The help of Mr. A. C. Glenday, Applied Mathematics Laboratory, was invaluable in the analysis of the data.

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REVIEWS OF SOME PAPERS READ AT THE 8TH INTERNATIONAL GRASSLAND CONGRESS AT READING, JULY 1960

IV. HERBAGE PRODUCTION AND MANAGEMENT*

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An international congress is an occasion to compare one's own ideas with those developed by people working in different environments. In this paper I should like to comment on those parts of the proceedings which could possibly modify our outlook on grassland management in this country.

This Congress was notable for reminders rather than revelations. To hear of grassland development in extensive cold or semi-arid regions made one all the more conscious of the potentialities of our temperate oceanic climate. One was also reminded at every turn that, if the best forage plants are to take full advantage of this climate, the soil must be conditioned; that its content of available plant nutrients must be husbanded very intelligently; and that in order to maintain an adequate and balanced supply of mineral nutrients it is nearly always necessary to supplement one or more of these by manuring.

As E. Crompton pointed out in his paper, the very act of using herbage plays a considerable part in maintaining the right soil condition for the right plants. In our own hill lands, incomplete decomposition of herbage leads to mat formation and impeded drainage. Some nutrients are locked up, some leached. Soil acidity rises, and this restricts the flora. The natural equilibrium of any permanent grassland where, for one reason or another, much of the herbage dies uneaten, tends to be a state of low productivity. A. S. Thomas, in what I thought to be one of the most spirited presentations of this congress, put forward a rational case for the use of fire in the extensive management of grassland, and he based his case partly upon the need to keep plant nutrients in circulation.

I thought some of the papers on range management, especially from North America, showed that the ecologists are still preoccupied with climatic adaptation. Thus it is considered that grazing pressure should be determined by the survival of climax species, i.e. those species which are dominant in the absence of domestic livestock. However tenable this theory may be at present for under-populated areas with a grassland climax, it hardly takes account of any factors other than selective grazing and trampling. It is of little more than academic interest in the vast and relatively populous areas of grassland in tropical Africa and Asia which were discussed by H. F. Heady and R. O. Whyte. There, even after a necessary reduction in stocking rate, the pasture may bear no more resemblance to climax vegetation than do good pastures in forest-climax situations. Its composition reflects not only stocking rate but also the system of grazing, burning, mowing, and the various methods of bush control. It also reflects soil condition. If none of the other factors can be manipulated so as to arrest the botanical degradation, there remains the possibility that manuring will. It will almost certainly modify the climax, especially if seed of appropriate species is introduced. This is borne out by the reports of improvement brought about in almost every sort of environment by the correction of soil

*Paper read before the British Grassland Society in London on 9 December, 1960. See pp. 160–73 of this Vol. for other papers in this series.

deficiencies, sometimes coupled with oversowing.

Australia has probably given us the most striking examples of the way in which a change in soil nutrient status may make a 'desert' fertile without irrigation. J. G. Davies gave us numerous fresh examples from tropical Australia, in which mineral nutrition could be said to be at least as significant as climate. Thus, grave doubt is thrown upon the concept that there is no substitute for climax vegetation in 'difficult' environments.

How does all this relate to our own grasslands of Britain? It suggests to me that we may be somewhat complacent about the value of indigenous plants as a means of exploiting the opportunities which our climate affords. The productivity of the 'climax' (or, rather, sub-climax) grasses of our best permanent pasture is easily surpassed in autumn and early spring by introduced grasses like Italian ryegrass and by more recently introduced perennial grasses, given adequate mineral nutrition. And provided it is possible to utilize it, winter pasture is as valuable to us as is dry-season pasture in the tropics.

Attempts to introduce better species into pasture by oversowing have rarely met with rapid success in Britain, despite every attention to manuring and management. It was tantalizing to learn of the relative ease with which white clover has been introduced into New Zealand tussock (G. S. Robinson and M. W. Cross), or lucerne into range grasses in Wyoming (D. F. Hervey). However, an optimistic note was struck by M. A. Sprague of New Brunswick in his review of chemical destruction of native species as a preparation for surface seeding. As J. G. Elliott (U.K.) observed, the technique is in its infancy, but recent developments suggest that it will find a place in grassland husbandry here as elsewhere. Nevertheless, the lesson from this congress was that good grass grows only on good soil, and that permanent improvement depends on the raising of soil fertility.

One entire session was devoted to nitrogen fertilizers and the nitrogen cycle. P. A. Linehan referred to nitrogen as "the master key to high grassland output". He and J. Lowe showed that, in Northern Ireland, grass/clover plots receiving 140 lb. N per acre each year for six years yielded no more protein in the last five years than similar plots receiving no nitrogen. D. W. Cowling and I find close agreement between these results and those from other parts of the U.K. In our own paper, however, we drew attention to the limitation imposed on yield by complete dependence on clover for nitrogen, under pasture conditions in the British climate. Given enough nitrogen, a pure grass sward may yield twice as much dry matter per acre in this climate. Both the instability of a high clover content and the apparent inefficiency with which nitrogen circulates under grazing conditions led us to suggest that zero-grazing might be the best means of exploiting the nitrogen-fixing potentialities of clovers or lucerne. P. D. Sears, in his paper on grass/clover relationships in New Zealand, described levels of fertility, built up on legume nitrogen and stock droppings alone, which were so high that stock suffered in health. But others from New Zealand saw similarities between their average conditions and ours.

Doubts were expressed about the wisdom of increasing yield at the expense of clover content. J. B. Washko (U.S.A.) had been unable to establish a difference in the performance of beef steers between mixed swards without N and grass swards with N. D. J. Moloney (Ireland), R. E. Blaser (U.S.A.) and W. W. Heineman (U.S.A.) quoted experiments in meat and milk production which favoured the grass/legume mixture.

In retrospect, I do not think we paid sufficient attention, in the formal discussion, to the use of nitrogen fertilizers for extending the grazing season. After all, this has probably been their chief application to date in this country. Later in the proceedings, however, J. Clarke (U.K.) was able to show that farmers using N at modest levels for this purpose could increase their profits, even though the total production of starch equivalent might be slightly reduced.

The problem of spreading pasture production into the winter or into drought was not neglected, but I think it could have been emphasized much more in the sessions on

plant breeding, appraisal and variety testing. I formed the opinion that both selection and appraisal are too much influenced by existing varieties. The difficulty of identifying many of the new varieties by agronomic characters shows how slowly we are now progressing in the cultivation of herbage plants with entirely different growth rhythms. The congress was not lacking in instances of plants taken into strange environments being, *at certain seasons*, more productive or of better quality than the best local forms. It is curious that nowadays when the plant breeder is presented with such a phenomenon his first thought seems to be, 'How can I introduce this character into the best of the existing varieties'? This gives him interesting and often, I suspect, difficult exercises in combining ability, but agronomically the result is usually a compromise. Sometimes it might be better if he were to select and breed for maximum production and quality at a certain time of year, without reference to growth at other times; and to leave the agronomist to find a way of incorporating the resulting variety into a mixture or system.

We heard frequent reference to 'seasonality', but there was little evidence of really bold thinking about filling the major seasonal gaps in herbage production. It was clear from papers by C. E. Wright, Ø. Nissen and E. Åkerberg that the need for compatibility with legumes is appreciated both by breeders of grasses and by those concerned with testing of varieties. I hope that before long we may have grasses capable of good response to nitrogen in autumn and early spring which are still readily compatible with legumes.

The discussions of plant physiology threw remarkably little light on management for herbage production. This only served to show what a large field of research has still to be explored. E. Huokuna of Finland described experiments in which herbage yield increased with the interval between cuts: but he noted that when the sward was harvested it paid to cut fairly low, partly, one inferred, in order to stimulate tillering.

V. Sadar said that in Slovenia rationed strip-grazing steadily improved a permanent pasture, which eventually yielded more starch equivalent per unit area than any other forage crop, including maize for silage. C. P. McMeekan had satisfied himself that some form of controlled grazing was necessary to achieve maximum output: but whether there is much to choose between the different systems of control remains, I believe, a matter for doubt. C. Line's experiment at Shinfield had shown no difference in milk production between strip and paddock grazing.

Reflecting upon the evidence presented at this Congress, I wonder if the system of defoliation has anything like the influence upon yield of herbage that its mineral nutrition has; or even if it is as important as the choice of herbage plants. I think it is fair to suggest that, where some control of grazing is already practised, we should be looking rather to manuring and plant introduction for a significant increase in pasture production.

With regard to the relative merits of grazing versus cut forage crops, a remark made by I. Arnon of Israel will bear repetition. It was this: 'The problem does not consist in a choice between harvesting by the cow as against mechanical harvesting, so much as in determining the type of forage which is most productive in a given environment'. The method of harvesting is itself part of the environment, and we have to determine which plants are best suited to mechanical- or zero-grazing in our climate before we can evaluate that system.

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THE INFLUENCE OF SEASONAL CHANGES IN LIGHT ENERGY ON LEAF AND TILLER DEVELOPMENT IN RYEGRASS, TIMOTHY AND MEADOW FESCUE

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The importance of leaf area as a determinant of yield in herbage crops is now widely realized. Selection for a rapid increase in leaf area might therefore be a useful approach to the problem of breeding for yield.

The present paper describes the seasonal changes in two important components of leaf area, rate of leaf and tiller production, in contrasting varieties of ryegrass, timothy and meadow fescue. The regular seasonal variation in these components in the glasshouse is shown to be determined primarily by available light energy, the species and varieties differing in their response to changes in light energy. The possibilities of selection for these components of leaf area are discussed, but it is pointed out that individual leaf size must also be considered.

INTRODUCTION

The importance of leaf area as a determinant of yield in herbage crops is now widely recognized (8), and growth analyses have shown that in ryegrass, as in several annual field crops, varietal differences in dry-matter accumulation in the seedling stage are based largely on variations in leaf area, there being little difference between varieties in net assimilation rate, i.e. photosynthetic efficiency (9).

Selection for a rapid increase in leaf area might, therefore, be a useful approach to the problem of breeding for yield. Appreciable genetic variation for such components as leaf size and rate of leaf and tiller production have already been found in ryegrass varieties (5). The responses of these components to such environmental factors as light and temperature are also important, and the present paper describes the effect of seasonal changes in light-energy on the pattern of leaf and tiller development in contrasting varieties of ryegrass, timothy and meadow fescue.

MATERIAL AND METHODS

The following contrasting agronomic varieties of ryegrass and timothy were studied, together with one commercial sample of meadow fescue. Their agronomic characteristics have been reviewed by Davies (7).

Ryegrass (*Lolium* spp.)
- Westerwolths from the Netherlands
- Italian from Northern Ireland
- Irish perennial from Northern Ireland
- Hunsballe perennial from Denmark
- Kent perennial from Kent

Meadow fescue (*Festuca pratensis*)
- Meadow fescue from England

Timothy (*Phleum* spp.)
- Scottish from Scotland
- S51 from certified stocks
- S48 from certified stocks
- Bd 2502 a late-flowering pasture selection from Aberystwyth
- S50 from certified stocks

All varieties were sown in the glasshouse under natural daylengths on the following dates:

1955: 2 November, 13 December (except Kent)

1956: 5 January, 13 March, 8 May, 6 July, 11 September.

An additional sowing was made on 13 December 1955 to study the effects of low intensity continuous supplementary light provided by 100-watt tungsten filament lamps, giving an intensity of 30–150 ft. candles at plant level.

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The glasshouse was heated from the beginning of the experiment until 31 March, and from early September onwards, except for a few days in the last week of January 1956. The mean temperatures at plant level throughout the experiment are given in Fig. 1 which also shows sunshine records from an adjoining site, and the hours of light from sunrise to sunset.

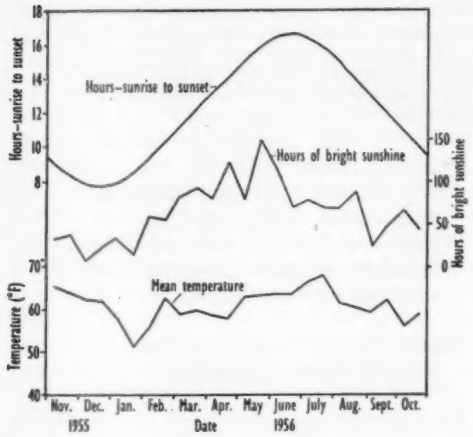

Fig. 1. Seasonal variations in temperature, hours from sunrise to sunset, and hours of bright sunshine during the experiment.

The following records of leaf and tiller development were taken at each sowing:

date of appearance of successive leaves on the main shoot up to the 7th leaf stage,
axillary position of the earliest tiller,
tiller counts at weekly intervals during seedling growth.

There was no competition for light or nutrients up to the 7th leaf stage under these conditions (17).

RESULTS

The pattern of leaf and tiller development in *Lolium* has been described by Mitchell (12, 13) and in *Phleum* by Langer (10), and the present observations agree with their accounts. During early vegetative growth, the rate of leaf appearance on each shoot is linear, provided that environmental conditions remain uniform, and there is a high correlation between the rates on the main and secondary tillers (5).

New vegetative tillers arise from buds in the leaf axils, but the node at which tillering starts depends on the variety and the environment. Tiller development in any axil does not usually begin until the leaf above it is fully expanded; the rate of tiller appearance is thus linear on each shoot.

New leaves and tillers are produced at a linear rate on the secondary tillers also, so that until competition begins, or floral initiation occurs, the increase in *total* number of leaves or tillers is exponential.

The number of tillers, and therefore of leaves per seedling, will thus depend primarily on the rate of leaf appearance per tiller, but will also be influenced by the node at which the earliest tiller is produced, and by the rate of expansion of available tiller buds.

Rate of leaf appearance

The seasonal changes in rate of leaf appearance are shown in Fig. 2. The seasonal variation is regular and similar for all varieties, with the slowest leaf production in the winter months and the fastest from the May sowing.

In the ryegrass group, which includes meadow fescue, Westerwolths is always more rapid than the others, and meadow fescue the slowest, but there are few regular differences between the other varieties. The timothy shows more rapid leaf production than the ryegrasses, especially in the summer sowings, but varietal differences are much less pronounced, although Scottish is always the fastest and Bd 2502 the slowest.

This regular seasonal variation suggests that rate of leaf appearance is controlled by either photoperiod or total light energy, both of which vary regularly through the year, rather than by temperature, which fluctuates less regularly in this experiment.

Tiller development

The potential increase in tiller number is determined primarily by the rate of leaf

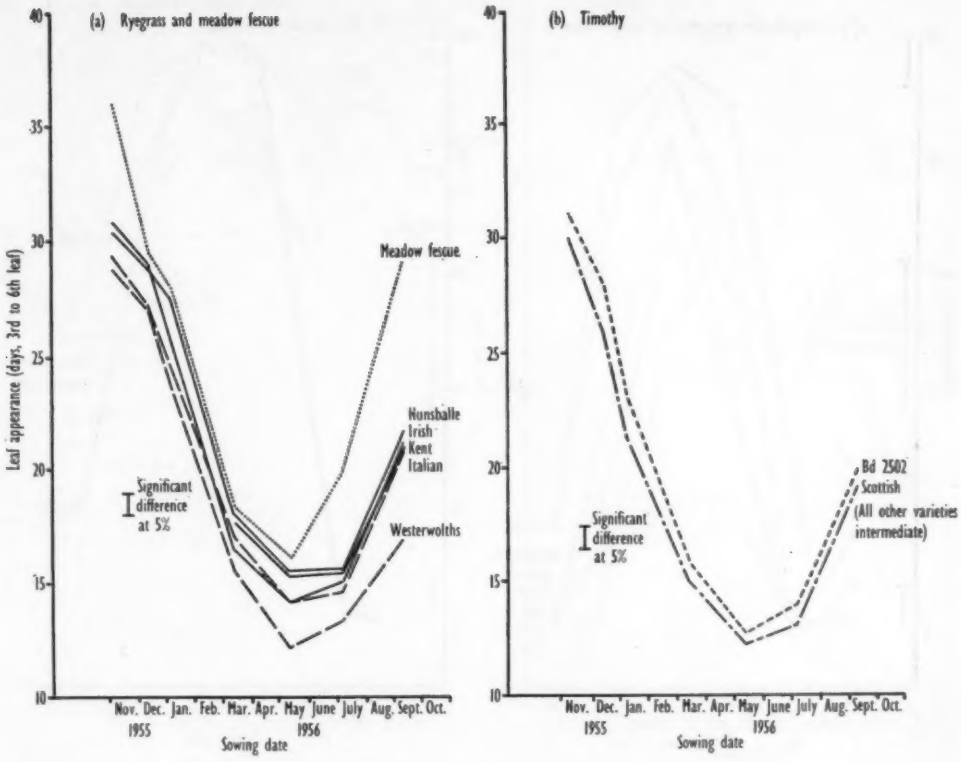

Fig. 2. Seasonal variations in rate of leaf appearance.
(a) ryegrass and meadow fescue.
(b) timothy.

appearance, but is strongly modified by the axillary position at which the earliest tiller appears and by the relative rate of tiller and leaf production on the shoot. Tiller development has therefore been expressed in three ways:

(i) the axillary position at which tillering begins (Fig. 3)

(ii) the exponential increase in tiller number between the 5th and 7th leaf stage (Fig. 4)

(iii) the resultant tiller number per seedling at the 6th leaf stage (Fig. 5)

(i) In the ryegrasses, nearly all plants produce a tiller in the axil of the second leaf, but the development of tillers at lower nodes depends on the variety and sowing date, as shown in Fig. 3a. The seasonal variation is again very regular, with the maximum development of coleoptile tillers in the summer sowings and the minimum in the winter. Marked varietal differences occur; the *L. multiflorum* group (Italian and Westerwolths) shows a greater development of coleoptile tillers at all sowing dates, while the perennial ryegrasses begin later and the meadow fescue latest of all. These varietal differences are borne out by the distribution of the first leaf tillers.

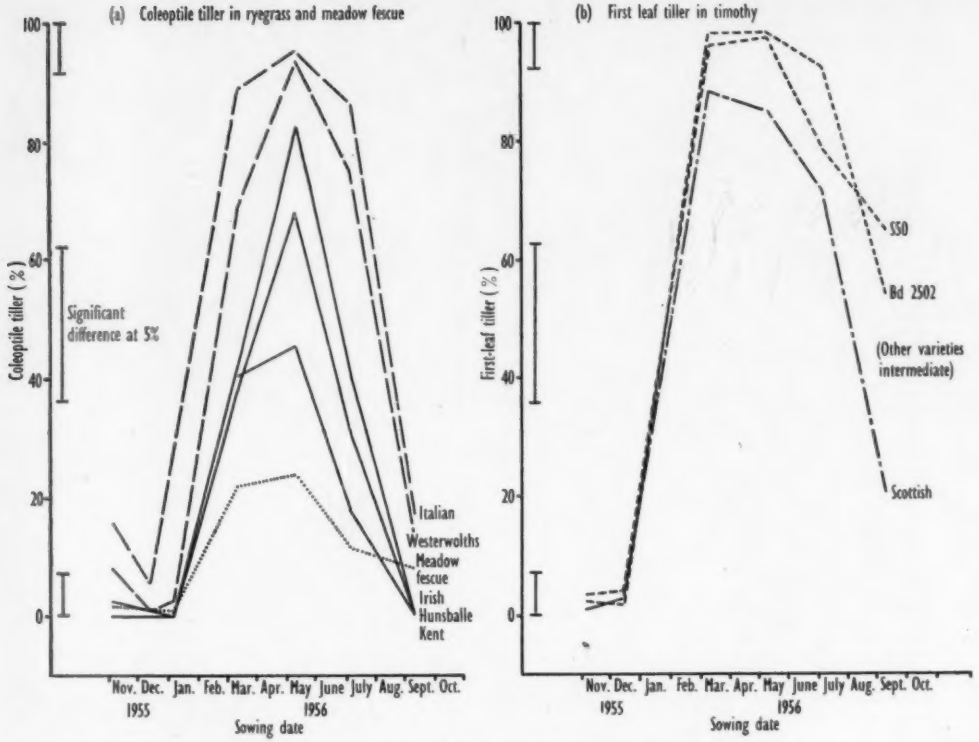

Fig. 3. Seasonal variation in position of earliest tiller:
(a) coleoptile tiller in ryegrass and meadow fescue
(b) 1st leaf tiller in timothy.

In timothy, no coleoptile tillers are formed under the present treatments, and the distribution of 1st leaf tillers is shown in Fig. 3b. There is again a regular seasonal variation, with strong inhibition of tillering at the lower axils in the winter sowings and the maximum development in the summer. No great varietal differences occurred, although the pasture varieties, S50 and Bd 2502, showed the greatest tiller development, and Scottish timothy the least.

(ii) The exponential increase in tiller numbers shown in Fig. 4 does not present such a regular picture. In all species the values are low in the November sowing and increase to a peak in the spring-sown seedlings. They decline during the early summer sowings and then reach another peak in the July sowing before falling again in the autumn-sown seedlings. The depression in the autumn and winter can be explained in terms of inhibition of tillering at the lower nodes, described above, but the marked summer decline remains to be explained.

Appreciable varietal differences were found in the ryegrasses, often in the reverse order from the initial level of tillering. Westerwolths and Italian, for instance, showed the slowest rate of exponential tiller increase, particularly in the summer. In Westerwolths, though not in

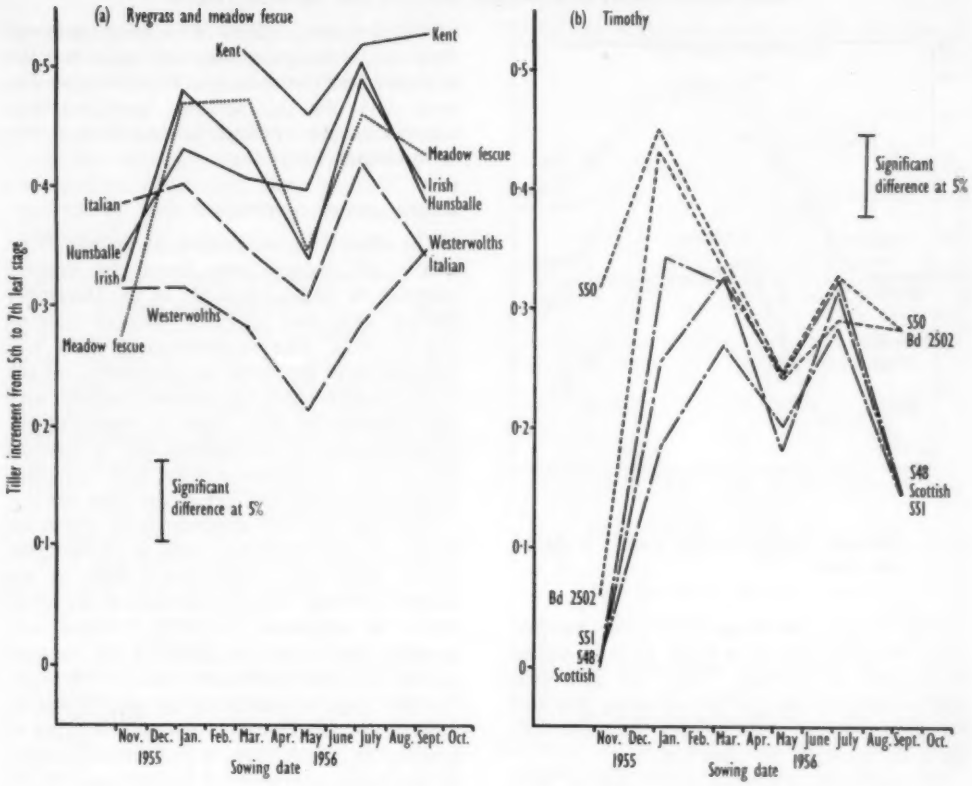

Fig. 4. Seasonal variation in exponential increase of tiller number from 5th to 7th leaf stage:
(a) ryegrass and meadow fescue
(b) timothy.

Italian, this may be due to floral initiation. The pasture variety Kent showed the highest tillering rate on this scale.

Timothy had lower exponential rates of tillering than the ryegrasses, particularly in the autumn and winter sowings, when tillering had hardly started by the 5th leaf stage. The pasture varieties, S50 and Bd 2502, were higher than the others in the autumn and spring but this difference was not maintained in the summer.

This rate of tillering on a leaf-appearance scale is evidently not necessarily related to the level at which tillering starts, and it shows no obvious relation to the light and temperature regime.

(iii) The final tiller number at the 6th leaf stage, which gives a measure of the ability of the plant to develop tillers from a standard number of primary axils (12), is given in Fig. 5. All the species show a similar seasonal variation, with low values in the autumn and winter sowings, increasing in the spring, remaining more or less at a plateau through the summer and declining again in the autumn.

In the ryegrass group, the highest values are given by Italian, largely because of the development of tillers in the lowermost axils. The lowest are Westerwolths and meadow fescue, the former because of floral initiation during summer and early autumn.

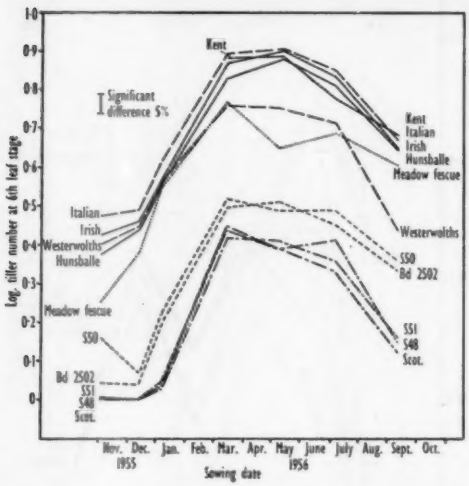

Fig. 5. Seasonal variation in tiller number at the 6th leaf stage.

The timothy shows a lower tiller number than the ryegrasses, as a result of their higher initial axil of tillering. They fall into two marked groups, the pasture varieties, S50 and Bd 2502, having more tillers than the hay varieties, Scottish, S48 and S51.

In conclusion, the rates of leaf and of tiller production both show a regular seasonal variation, although species and varieties differ in their exact performance. It remains to discover how far this seasonal variation is a response to photoperiod, to total light energy or to temperature.

Response to photoperiod

The effect of photoperiod, as distinct from total light energy, was tested by supplementing the natural daylight of the December sowing with low intensity filament lighting (see p. 299). This supplementary light was fully effective for floral development; all the Westerwolths seedlings headed rapidly with leaf numbers of 5–6. Table 1 compares the effects of natural photoperiod and continuous light in the December sowing with the high-intensity summer daylight of the May sowing.

The rate of leaf appearance is increased slightly by supplementary light in all varieties, but is still considerably lower than in the summer sowing. Tiller production at the lower nodes is increased in both ryegrass and timothy, but is still far short of the summer values. The tiller increment from the 5th to the 7th leaf stage is unaffected by supplementary light in the ryegrasses and the pasture types of timothy, in which tillering had already started at the lower nodes, but it is increased in the

TABLE 1. Effect of low intensity supplementary light on leaf and tiller production

	Sowing date and treatment*				
	Dec. N.D.	Dec. C.L.	May N.D.	Sig. diff. at 5%	at 1%
Days 3rd–6th leaf					
Ryegrass	28·6	26·7	15·9	1·9	2·9
Timothy	26·6	23·8	12·4	0·8	1·1
Tillers at lower nodes (%)					
Ryegrass (coleoptile)	0·0	6·3	67·5	32·5	49·2
Timothy (1st leaf)	1·0	32·0	92·2	18·6	27·1
Tiller increment 5th–6th leaf					
Ryegrass	0·39	0·36	0·35	Not significant	
Timothy	0·13	0·20	0·22	0·06	0·08
Log. tiller number at 6th leaf					
Ryegrass	0·47	0·56	0·84	0·13	0·20
Timothy	0·02	0·23	0·44	0·07	0·11

*See text for details

hay-timothy types. The tiller number at the 6th leaf stage thus increased slightly, though again the values are far below those from the May sowing.

The seasonal variation in leaf and tiller production evidently cannot be attributed to photoperiod alone, and the effects of total light energy and temperature remain to be investigated.

Influence of light energy and temperature

Light energy was recorded as the mean hours of light from sunrise to sunset, and the mean temperature was obtained from the continuous thermograph record. The multiple regressions of (i) rate of leaf appearance, measured as *leaves per week*, and (ii) log. tiller number at the 6th leaf stage on these two variables were then calculated for the period from the 5th to 7th leaf appearance. Italian and Irish perennial ryegrass, meadow fescue, Scottish and S50 timothy, were used in these calculations to cover the genetic range in the material.

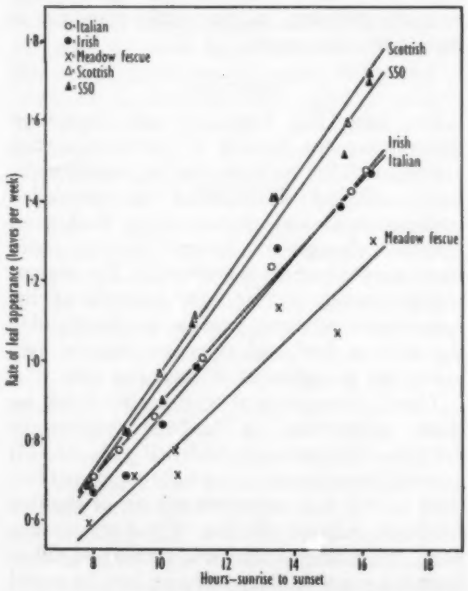

Fig. 6. Regression of rate of leaf appearance on light-hours (sunrise—sunset).

TABLE 2. Regressions of leaf and tiller production on light and temperature

Leaves per week (Y)	
Italian	Y=0·093 L — 0·029 (±0·003)
Irish	Y=0·102 L — 0·149 (±0·006)
Scottish	Y=0·120 L — 0·220 (±0·005)
S50	Y=0·116 L — 0·212 (±0·007)
Meadow fescue	Y=0·080 L — 0·046 (±0·010)
Log. tiller number at 6th leaf stage (Y)	
Italian	Y=0·079 L — 0·173 (±0·009)
Irish	Y=0·083 L — 0·234 (±0·005)
Scottish	Y=0·083 L — 0·722 (±0·020)
S50	Y=0·077 L — 0·515 (±0·018)
Meadow fescue	Y=0·082 L — 0·301 (±0·017)

L=hours from sunrise to sunset

(i) *Leaf appearance.* In all cases the multiple regression of rate of leaf appearance on mean hours of light was highly significant but that on temperature was not. The simple regressions of leaf appearance on light-hours have therefore been used (Table 2, Fig. 6).

The relationship between leaf appearance and hours of light appears to be linear, and no saturation level has been reached even in the summer sowings, possibly because these plants were grown in a glasshouse which transmitted only 60–70% of daylight.

There are marked differences between the species. Timothy produces leaves more rapidly than ryegrass over most of the range, and shows a more rapid increase with increasing light. Meadow fescue, on the other hand, produces leaves more slowly throughout, although the rate of increase with light is similar to that of the ryegrasses. No varietal differences were detected between the ryegrass or the timothy varieties tested. Westerwolths ryegrass, which produces leaves most rapidly in the summer sowings (Fig. 2) cannot be validly compared with the other varieties, as floral development

had started by the 6th leaf stage in the summer and early autumn.

(ii) *Tillering*. In all varieties tiller number at the 6th leaf stage increases with light-hours per day up to a maximum at 13 hrs., followed by a plateau or even a slight decrease.

The multiple regressions of tiller number (on a log. scale) on light and temperature have, therefore, been calculated only for the increasing portion of the curve up to about 13 hrs. There was again no significant effect of temperature over the present range, and the simple regressions of tiller numbers on hours of light were therefore calculated (Table 2,

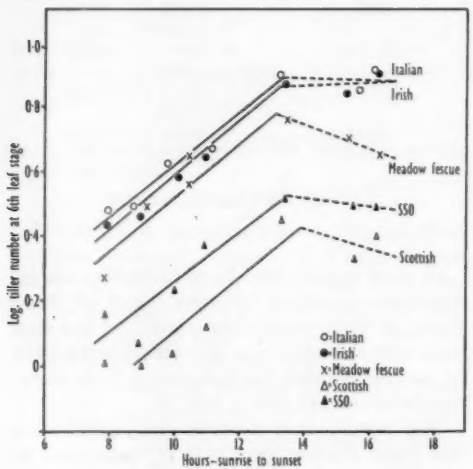

Fig. 7. Regression of tiller number (at 6th leaf stage) on light hours (sunrise—sunset).

Fig. 7). The regression on light-hours was significant in all cases, and marked species differences occurred. The ryegrasses gave the highest values, followed closely by meadow fescue, with timothy much lower; the pasture type S50 showed a higher tiller number throughout than the Scottish hay variety.

The slopes of the regression lines are similar in all varieties and the maximum tiller number was attained at the same level of light in each case. The varietal differences in response to light energy were based largely on the axillary position at which tillering started, this being much earlier in the ryegrasses than in the timothy types.

These calculated regressions also give an accurate prediction of rate of leaf appearance and tiller number for the same varieties grown in the same glasshouse in later years. They do not, however, apply to material grown outdoors, or in other glasshouses with different orientation and light transmission (18). For instance, the corresponding regression for leaf appearance of several ryegrass varieties grown in a small north-south house with lower light transmission (3), was $Y = 0{\cdot}076\ (\pm 0{\cdot}004)\ L + 0{\cdot}042$, a considerably slower rate throughout. For more critical comparisons the present approximate measure of light energy, i.e. hours from sunrise to sunset, must be replaced by a continuous record of light energy, as pointed out by Wit (19).

Even so, we can conclude that over the present glasshouse environments with a small temperature range, both the rate of leaf appearance and the level at which tillering starts, and hence the final tiller number, are limited largely by light energy, the species and varieties differing in their light response to these two components.

DISCUSSION

The overriding effects of light energy in determining the growth of herbage species are now well known from shading experiments, from artificial illumination in controlled environments, and from the correlation of seasonal changes in natural daylight with plant growth and development (1). The present results provide yet another example of the importance of light energy in determining the rate of leaf and tiller production, two important components of total leaf area.

This is in agreement with earlier work on these components in herbage grasses. In ryegrass, for instance, Mitchell (12, 13, 14) showed that decreasing the light intensity from 2000 to 700 ft.c. in growth rooms, or shading outdoors, reduced the rate of leaf appearance and also inhibited the development of tillers from the lower axillary buds. In fact, he stated that light energy was the main environmental factor limiting tiller number at an equivalent

leaf age. A similar dependence of rate of leaf appearance and tiller development on light energy was later shown for cocksfoot and *Paspalum* (15), a reduction of light intensity from 0·65 to 0·20 daylight decreasing the rate of tissue formation by about one-third.

Temperatures outside the present limits will of course affect leaf and tiller production. In many North European grasses such as ryegrass, cocksfoot, *Agrostis* and Yorkshire Fog, Mitchell (16) finds that the rate of leaf appearance increases up to about 60°F, remains more or less steady till 75°F and then falls again, while the tropical *Paspalum* has a higher optimum, about 85°F, and leaf appearance declines rapidly below this figure. The optimum temperatures for tiller production seem to be slightly lower; an increase from 50° to 65°F inhibited tillering at the lower nodes in perennial and short-rotation ryegrass (12, 13) and similar effects have been recorded for cocksfoot and tall fescue (4).

These effects of light and temperature on leaf and tiller development must ultimately operate through the rates of leaf and bud initiation at the apical and axillary meristems. In ryegrass, serial dissections show that the rate of leaf appearance is related to the rate of initiation (4), although leaf initials are regularly built up on the shoot apex in advance of leaf expansion, while in the cucumber Milthorpe (11) found that the rate of leaf appearance is proportional to that of initiation, and that both are strongly dependent on light energy.

Mitchell (12, 13) and Milthorpe (11) thus suggest that light energy influences the rate of leaf initiation through its effect on the rate of assimilation in the newly-expanding leaves and in the enclosing leaves of the terminal bud. The inhibition of tillering at the lower nodes by low light intensity may also be attributable in part to lack of available carbohydrate at the axillary meristems (13).

Both leaf and tiller development are thus strongly influenced by light energy, but from the breeding and selection standpoint, it is genetic variation in these components which is of interest. In the present work, the rate of leaf appearance, although varying *between* the three species, ryegrass, timothy and meadow fescue, seems remarkably constant *within* the species, even between such contrasting varieties as Italian- and Irish-ryegrass. A comparison of a wider ecological range of material grown in controlled environments (4) confirms this uniformity of rate of leaf appearance under optimum light and temperature conditions, but reveals marked varietal differences in both ryegrass and cocksfoot when grown under more extreme temperature regimes.

By contrast, in a study of the genetic variation *within* three ryegrass varieties (5, 6) rate of leaf appearance proved to be highly heritable, and selection, now in the third generation, produced a marked response well outside the original varietal range. There was, however, a strong negative genetic correlation between leaf appearance and leaf size, and so selection for leaf appearance alone gave no regular increase in dry weight per plant.

The rate of tiller development, on the other hand, as determined by the level at which tillering begins, differs markedly between varieties. In ryegrass, the pasture varieties S23 and Melle show a greater inhibition of the basal tillers, particularly at low light intensities, than do such hay varieties as Irish, New Zealand and Devon Eaver (4). In timothy, however, the pasture types, S50 and Bd 2502, begin tillering at lower nodes than the more erect hay varieties. In cocksfoot the Portuguese diploid (*D. glomerata* subsp. *lusitanica*), which is very productive in winter (2) proves to be relatively high-tillering at low light intensities (4). There thus exists genetic variation either between or within varieties for the rate of both leaf and tiller development in the seedling stage.

The value of this genetic variation to the breeder depends on the extent to which such seedling measurements can be related to performance in a competitive sward, and this problem is discussed in detail elsewhere (5). The ability to produce leaves and tillers under low light intensities, for instance, could be valuable in the field from late autumn to early spring, and is also important in making full use of the low intensity light at the base of a dense sward (14, 15).

It must be remembered, however, that dry-matter production in the sward is based on total leaf area, and that rate of leaf- and tiller-production are only two components of this total. Individual leaf size is also important, and in fact Cooper and Edwards (5) find that most of the variation in total leaf area between Italian and perennial ryegrass in the seedling stage is based on leaf size, rather than on overall rate of leaf production.

These preliminary results therefore emphasize the importance of more critical studies of the genetic variation in total leaf area and its components, and, in particular, their response to various levels of light energy and temperature. As a result it should be possible to select for the optimum use of available light energy under different light and temperature regimes.

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THE PRODUCTION AND UTILIZATION OF WINTER GRASS AT VARIOUS CENTRES IN ENGLAND AND WALES, 1954–60

II. Livestock utilization

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The performance of livestock on winter grass was studied at eighteen sites in England and Wales from 1957 to 1960.

Beef cattle generally gained weight while grazing winter grass. They invariably did better than similar animals overwintered on the normal feeding regime of the farms concerned.

At 8 centres winter grass was utilized by dairy cows. Calculations indicated that the grass provided a valuable portion of their feed.

The general condition and health of livestock grazing winter grass were satisfactory at all centres.

Damage caused by poaching was largely prevented by controlled grazing.

The production and utilization of winter grass had no adverse effects on sward recovery in the subsequent spring.

INTRODUCTION

The results discussed in Part I (Baker *et al.*, 2) of this paper indicated that winter grass could be grown under a wide range of environments in England and Wales. The data were concerned with herbage production only; the experiments were not designed to study the utilization of the grass by stock. Encouraging results were obtained with beef cattle grazing winter grass by Hughes *et al.* (5) and Alder (1). Animal performance is one of the major factors involved in assessing the value of winter grass, although waste of the grass and damage caused to the sward by poaching are also important: all may be affected by climatic conditions. Therefore, in addition to the experiment to measure winter yields of herbage during 1954–8, livestock performance on winter grass was studied on farms in different parts of the country from 1957 to 1960.

TREATMENT AND MANAGEMENT

In the trials discussed in Part I (2), cocksfoot, rested from mid-August and top-dressed with 52 lb. per acre of nitrogen, was the most useful grass for winter grazing. To study animal performance under such grazing conditions over an extended period, this resting and fertilizer treatment was applied to whole fields, in contrast with the smaller areas used in the majority of the herbage-production trials. As far as possible cocksfoot-dominant swards were chosen, but in some instances other swards based on perennial ryegrass or on meadow fescue/timothy were used.

Beef stores were chiefly used for the trial, but dairy cows were employed at some centres. In the case of the former, liveweight changes were followed throughout the period of winter grazing and, where possible, the animals were compared with a group of similar cattle being overwintered under the normal feeding regime of the farm concerned: no attempt was made to influence the methods of feeding these control groups. The performance of beef stores was followed at six centres in 1958/9 and at four during 1959/60.

TABLE 1. The performance of beef cattle on winter grass

Year	Centre	Cattle	Control group feeding	Winter-grass group Sward type, acreage and herbage yield (dry-matter), plus any supplementary feeding	Duration of grazing by winter-grass group	Average live weight in lb. at beginning of grazing	Changes in live weight (lb. per head)	
							Control	Winter grass
1958/9	North Yorkshire	18-month old Shorthorn steers 7 per group	Grazing old ley, plus 10 lb. hay per head per day	Cocksfoot dominant, timothy, meadow fescue 7 acres 1380 lb. per acre	14 Nov to 30 Dec	980	+ 1	+35
	Northamptonshire	18–21 month old Hereford and Hereford × steers 5 per group	21 Nov to 12 Dec grazing only; 12 Dec to 19 Dec grazing plus 6 lb. hay per head per day; 19 Dec to 7 Jan (indoors), 8 lb. hay, 16 lb. oat straw, 1 lb. meal per head per day	S26 cocksfoot in drills 14 in. apart 6 acres 1510 lb. per acre 15 Dec to 7 Jan 1 lb. meal per head per day	21 Nov to 7 Jan	960	−80	−50
	Wiltshire	In-calf heifers 11 Friesian, 2 Shorthorn and 3 Hereford	No control	Cocksfoot-dominant ley 11½ acres 2360 lb. per acre	19 Nov to 7 Jan	950	No control	+21
	Devon I	15–18 month old Friesian and Friesian × Hereford steers 5 in group	No control	Cocksfoot 5 acres 2850 lb. per acre	18 Nov to 8 Jan	630	No control	− 4
	Devon II	18-month old Friesian 8 in group	No control	Cocksfoot/timothy/meadow fescue 7½ acres 1960 lb. per acre	18 Nov to 3 Dec	730	No control	+47
	Merioneth	Welsh Black and Welsh Black × Hereford × Shorthorn heifers 8 in group	No control	Cocksfoot 6 acres 1860 lb. per acre 29 Dec to 16 Jan 4 lb. cereal and beet pulp meal per head per day	17 Nov to 16 Jan	960	No control	+38
1959/60	North Yorkshire	24-month old Shorthorn steers 6 per group	Grazing plus 70 lb. silage per head per day (21% dry-matter, 12% crude protein)	Cocksfoot/timothy/meadow fescue 11 acres 910 lb. per acre 3 lb. hay per head per day	19 Nov to 31 Dec	934	− 8	+88
	Wiltshire	Friesian, Shorthorn and Hereford heifers 9 per group	Grazing plus 3 lb. straw per head per day	Cocksfoot-dominant ley 9 acres 760 lb. per acre	13 Oct to 2 Dec	880	−10	+50
	Devon I	Friesian bullocks 8 per group	30 Oct to 7 Nov strip-grazed kale plus 3 lb. oat straw per head per day; 8 Nov to 1 Dec strip-grazed kale plus 6 lb. oat straw per head per day	Timothy/meadow fescue 7 acres 710 lb. per acre 30 Oct to 14 Nov 3–6 lb. straw per head per day	30 Oct to 1 Dec	780	−40	+ 6
	Devon II	Friesian bullocks 6 in group	No control	Cocksfoot-dominant ley 5 acres 600 lb. per acre	30 Oct to 1 Dec	800	No control	+13

Records of the milk yield and of the amount of supplementary feed given to the dairy cows were obtained from four centres which were concerned primarily with the herbage production trials of 1957/8, from two centres in 1958/9 and from two in 1959/60.

DISCUSSION OF RESULTS

Beef cattle

The results are given in Table 1. Conditions for herbage growth were extremely good in the autumn of 1958 and yields of dry matter ranging from 1380 to 2850 lb. per acre were obtained in November. The swards were stocked at one beast per acre from about mid-November to the end of December or early January. In 1958/9 control groups were available at the N. Yorkshire and Northamptonshire centres and were fed according to normal farm practice. At the former centre the control cattle just maintained their live weight, and those on winter grass showed an average gain of 35 lb. per head. At the latter centre both groups lost weight, the greater loss being that of the control group. At the remaining four centres, where no control group was available, one of the Devon centres indicated a slight loss in live weight: the second Devon centre gave an increase of 47 lb. per head; those in Wiltshire and Merioneth gave gains of 21 and 38 lb. per head, respectively.

The autumn of 1959 was dry, following an extended drought during the summer. This resulted in poor growth of herbage; yields of dry matter ranged from only 600 to 910 lb. per acre at the start of winter grazing. The late autumn and early winter were, however, relatively mild and grass continued to grow late in the year. As a result the cattle did extremely well on the limited amount of herbage available. Because of the shortage of keep on the individual farms, winter grazing began earlier than in 1958/9, except in N. Yorkshire where grazing dates were similar in the two years. Stocking intensity was again similar to that of 1958/9, except in N. Yorkshire where the stocking rate was approximately half and where 3 lb. of hay were fed to each animal daily to supplement the grass. Control groups were available at three centres, all of which showed a loss in live weight ranging from 8 to 40 lb. per head, while at all four centres the cattle on winter grass gained from 6 to 88 lb. per head. In the case of the N. Yorkshire centre, there was a live-weight gain of over 1½ lb. per head per day.

The general condition of the beef cattle on winter grass was satisfactory and was acceptable to the farmers concerned. None of the animals managed under the normal winter feeding practice of the farms did as well as expected, thus emphasizing the need for and the value of periodical weighing of beef cattle at all stages of growth and fattening. This procedure will allow their progress to be properly assessed and related to the level of feed given.

Dairy cattle

At the centres with dairy cows it was possible, to some extent, to follow the performance of the cows under a winter-grass regime during the course of the herbage production trials of 1957/8, as well as from 1958 to 1960. Estimates of the amount of herbage available for the three winter-grazing periods, the amount of supplementary feed given and the milk produced are shown in Table 2.

Herbage dry-matter yields at three out of the four centres recorded in 1957/8 were fairly satisfactory, ranging from 1000 to 1420 lb. per acre. The estimated production of milk from grass, calculated according to the system recommended by the British Grassland Society (3) was 2 gal. per cow per day at the Cumberland centre and 3½ gal. per cow per day at the Essex centre. At the Flintshire centre it was considered that the milk yield increased slightly. In Lancashire a saving of 10 lb. of hay per cow per day was attributed to winter grazing.

In 1958/9 dry-matter yields of herbage were again satisfactory, 1560 lb. per acre at the Essex centre and 2610 lb. per acre at the Lancashire centre. The former resulted in a production from winter grass of 2¾ gallons per cow per day and the latter in a saving of 25 lb. of kale and 3 lb. of hay per head per day.

TABLE 2. The performance of dairy cattle on winter grass

Year	Centre	Cattle	Sward type, acreage, and herbage yield (dry-matter)	Grazed From	Grazed To	Additional feeding per cow per day	Milk production per cow while on winter grass (gal.)	Estimated production from winter grass (gal. milk per cow per day)*
1957/8	Lancashire	16 Friesian	Cocksfoot 4½ acres 1050 lb. per acre	29 Jan	10 Mar	20 lb. turnips 10 „ hay 3½ „ dairy cake per gal.	Previous level maintained	Replaced 10 lb. of hay per cow per day
	Essex	40 Ayrshire	Cocksfoot 8 acres 1110 lb. per acre	13 Dec.	28 Dec.	7 lb. hay 3 „ barley meal 3 „ wheat	3·5	3·5
	Cumberland	56 Friesian	Cocksfoot 8 acres 1420 lb. per acre	22 Nov	10 Dec	4 lb. dairy cake 4 „ crushed oats 40 „ turnips 20 „ turnip tops 6 „ straw 12 „ hay	4·5	2·0
	Flintshire	45 Shorthorn	Cocksfoot 6 acres 1000 lb. per acre	12 Feb	12 Mar	Hay plus concentrates (no details available)	Increased slightly	No details (13 heifers also grazed for 1 week)
1958/9	Lancashire	19 Friesian	Cocksfoot 4½ acres 2610 lb. per acre	22 Nov	27 Dec	No details available	Previous level maintained	Replaced 25 lb. kale and 3 lb. hay per cow per day. (Also grazed by bullocks)
	Essex	40 Ayrshire	Perennial ryegrass 7 acres 1560 lb. per acre	21 Nov	18 Dec	3½ lb. hay 5½ „ cereals 2 „ high protein	2·75	2·75
1959/60	Lancashire	8 Friesian	Cocksfoot 4½ acres 680 lb. per acre	2 Dec	9 Jan	36 lb. turnips 4 „ hay 5½ „ straw 4 „ dairy cake per gal.	3·0	1·0
	Cornwall	21 Guernsey & Friesian	Perennial ryegrass 7½ acres 930 lb. per acre	26 Oct	18 Nov	2 lb. hay	2·0	2·0 plus major part of maintenance

*Calculated from system recommended by British Grassland Society (2)

Herbage dry-matter yields were lower in 1959/60. The Lancashire centre recorded a yield of 680 lb. per acre of dry-matter and produced 1 gal. of milk per cow per day during grazing. The centre in Cornwall gave 930 lb. per acre and provided maintenance and 2 gallons.

At all centres, the condition of the dairy animals on winter grass was satisfactory and the farmers were impressed with the results obtained.

Utilization of grass

It was clear from these trials that when utilizing winter grass undue waste must be avoided where possible. Generally, the greater the herbage yields, the wetter the season, and the heavier the soil the more likely is damage to the sward and waste of grass. Both could be reduced to negligible proportions by the control of grazing. The most satisfactory was to use an electric fence moved daily and to bring up a back fence within four or five days of the grazing. Such a system was most suitable for use with dairy cows, but with beef cattle good results were obtained by adopting a block-grazing technique designed to give a grazing area sufficient to carry the stock for a week at a time. Certain of the centres in these trials were situated on the heavy Gault and Lias clays where the swards were sown to lucerne and cocksfoot in alternate drills. Here poaching of the land by the grazing stock was reduced to a minimum, thus confirming the results of Hughes (4).

During the spring of 1958, herbage yields of swards grazed the previous winter were assessed, as were those of comparable areas not winter-grazed. The results indicated no consistent effect from the application of nitrogen in autumn, or from autumn resting, on the herbage dry-matter yields obtained the following spring. The production and utilization of winter grass had no adverse effect on subsequent spring recovery.

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COMPARISONS OF GRASS VARIETIES FOR SURFACE SEEDING UPLAND PASTURE TYPES

II. Deep peat

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Two deep peat deposits, one in a high-rainfall area, were surface seeded with a number of grass varieties. Their sward development and general agronomy are described. Differences in performance are associated with moisture supply and severity of winter conditions. Tall fescue, red fescue and timothy gave good results at both centres.

INTRODUCTION

In Scotland the estimated area of peat more than two feet thick is about two million acres (2). Blanket bog and hill peat predominate, but considerable areas of raised moss occur in the Midland Valley. The reclamation of peat has long aroused the interest of improvers. Initially, emphasis was on full scale reclamation for grass and crop production, e.g. schemes in Lewis (5) and Lanarkshire (6). Surface seeding was pioneered in the 1920's at Muirfad (7) and more recently at Birkhill (1); in the north of Scotland the technique has been described by Grant *et al.* (3).

The potential of peat soils for low cost pasture production is now more generally appreciated although it is difficult to estimate, on the basis of present knowledge, the area which might respond to such treatment. The present account deals with results from two similar deep peat deposits. The one at Birkhill, Lanarkshire is a low moor basin peat in the raised moss stage, typical of many in the Midland valley. The other is a basin peat at Lephinmore Farm, Argyllshire, an area of much higher rainfall in the general region of blanket bog development.

EXPERIMENTAL

The layout, varieties, seed rates and methods have already been described (4).

Soils and vegetation

Both centres lie at an elevation of 700 feet and have the characteristics shown in Table 1. The vegetation at both sites was dominated by *Calluna vulgaris*, with *Sphagnum* spp. and *Eriophorum vaginatum* abundant, and *Erica tetralix* and *Eriophorum angustifolium* occasional. At Lephinmore *Molinia caerulea* (frequent), *Trichophorum caespitosum* and *Narthecium ossifragum* (occasional) were also present.

Pretreatment

Originally, both sites were open to uncontrolled grazing at a very low intensity. "Sheep drains" had been cut many years earlier, but there was no evidence that this had modified the vegetation materially and by

TABLE 1.

	Peat depth	pH	Loss on ignition	Lime requirement	K_2O	P_2O_5
Lephinmore	12 ft.	4·4	90%	High	Medium	Very low
Birkhill	12–15 ft.	3·7	96%	High	Medium	Very low

*Now at the Welsh Plant Breeding Station, Aberystwyth.

1957 their efficiency was negligible. The areas had not been burnt for some years and the *Calluna* at both sites was about 12 in. high.

Pretreatment was as shewn in Table 2.

TABLE 2.

Lephinmore

1957

9 April—Burnt. Very satisfactory.
21 and 22 May—3 tons per acre ground limestone. 25 cwt. per acre low grade basic slag. 1 cwt. per acre nitro-chalk. Seed sown. Sheep driven over area to tread in seed.
14 November—Grazed, 19 ewes for 4 days.*

Birkhill

1957

10 April—Burnt. Fairly satisfactory.
23 May—Rotavated. Thick patches of dry *Sphagnum* remained.
24 May—3 tons per acre ground limestone.
23–25 July—6 cwt. per acre superphosphate. 1 cwt. per acre nitro-chalk. Seed sown. No autumn grazing.* The best growth was $<2\frac{1}{2}$ in. high.

*Total enclosed area approximately 0·6 acres.

The seed bed was poor at Lephinmore, owing to hummocks and hollows and extensive patches of dry *Sphagnum*. At Birkhill rotavation without rolling induced a "fluffy" dry surface.

Management

A top dressing of $4\frac{1}{2}$ cwt./acre of C.C.F. ($5 : 12\frac{1}{2} : 12\frac{1}{2}$) was applied in spring 1958 and no further applications were made.

Both sites were enclosed and Lephinmore was grazed with sheep 3–4 times each year. At Birkhill, the situation of the plots and availability of stock made it impossible to adhere to a predetermined plan and the management was mainly a combination of cattle grazing and cutting.

RESULTS

A. Lephinmore

Early establishment

Initially the surface was very dry, particularly on the *Sphagnum* patches. Three months after sowing, timothy, cocksfoot and to a lesser extent ryegrass, Yorkshire fog and meadow fescue were of some grazing value. Regenerating vegetation largely obscured the remaining varieties and since these seedlings were small and easily pulled out of the peat, grazing was deferred until late autumn.

In late October most plots were dominated by *Molinia* together with *Calluna*, *Erica*, *Trichophorum* and *Eriophorum*. On the "unsown" plots these species formed an 85% ground cover. The outstanding variety was Yorkshire fog (48% ground cover). Ryegrass, cocksfoot, timothy and the meadow grasses, with 20–25% cover, were of useful grazing value. The remaining varieties had a very slow rate of development. White clover was fairly uniform on all plots, with a cover of 10%. The area was grazed hard and uniformly in mid-November and rested during winter.

Sward development

In spring 1958 the regenerating native species offered little competition to the developing grasses, even those of low vigour in the previous autumn. Despite this, cocksfoot, red fescue, S170 and foxtail had ground covers of <30%. The other varieties lay between 35 and 45% cover, except Yorkshire fog and S50 which, at nearly 60%, were much superior (LSD = 11%). A rapid improvement was seen as the year progressed and all the varieties reached a pronounced peak in autumn. At this time unsown species contributed only 10–20% to the grass plots (except foxtail = 40%) and *Molinia* had been grazed out.

The rapid progress of those varieties with slow initial rates of establishment was a striking feature in 1958. This, and subsequent behaviour, are illustrated in Fig. 1.

A subsequent reduction in the high tiller density was to be expected during winter when the water table was constantly at the surface. By spring 1959 sward deterioration was well marked on all plots except S50 and bent, though most of the varieties were still satisfactory with ground covers between 40 and 70% (Fig. 1). Cocksfoot, Scots timothy and S24 had decreased to a point where their value was much impaired, while foxtail was reduced to 10% cover and did not improve later. A general sward improvement up to the end of July was apparently not retarded by dry conditions in May. Later, although surface

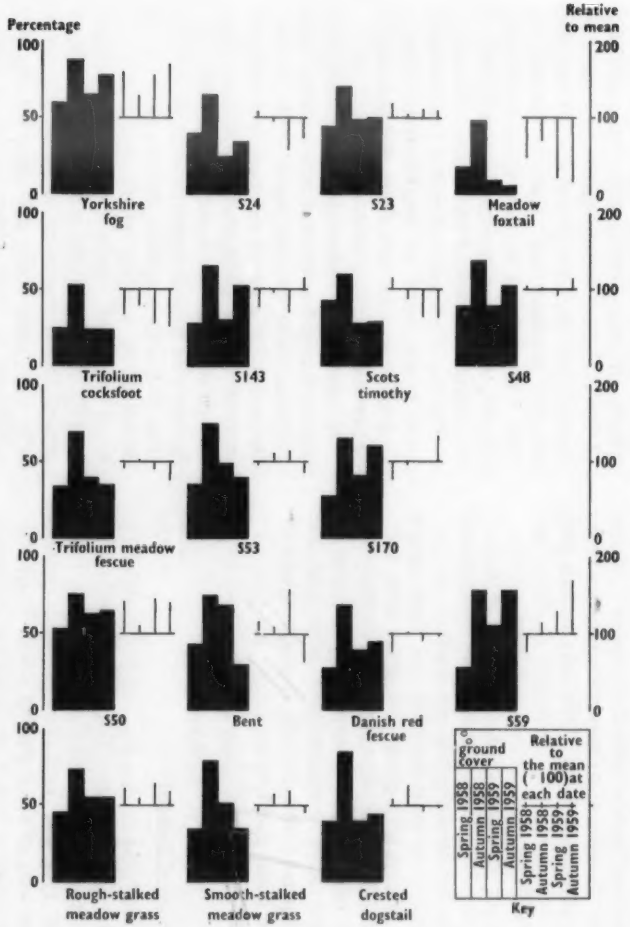

Fig. 1. Lephinmore site. Sward development—the contribution of sown grass to the ground cover 1958–59.

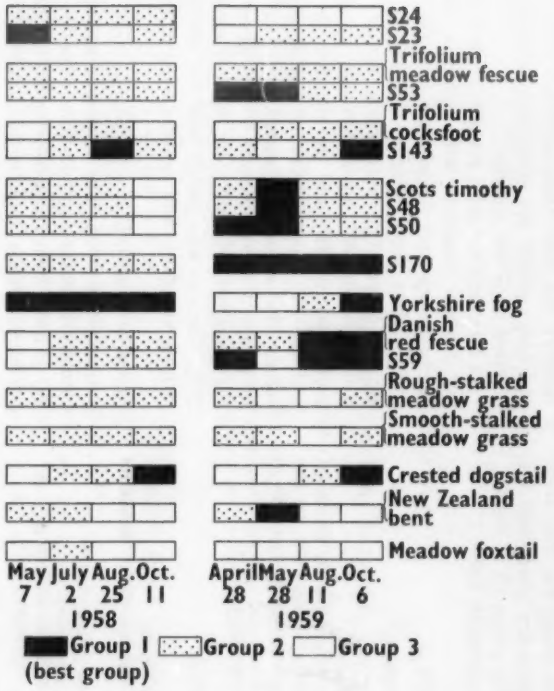

Fig. 2. Lephinmore site. Relative productivity—three classes based on the mean value at each date. (Full explanation in the text).

conditions were never excessively dry for long periods, the failure of many varieties to maintain this progress is attributed to marked surface drying which took place in August and September.

The performance of white clover was highly satisfactory. It reached a peak in August 1959 when the clover plots had a density of 50–60%.

By the end of 1959 the contribution of native species to the sown plots varied from 10–20% in the best group to 45% with S24 and Trifolium cocksfoot.

The outstanding features of sward development were:

(a) The rapid establishment and maintenance of a dense sward throughout by Yorkshire fog, S50 and, to a lesser extent, S23 and RSMG.

(b) After a slow start the rapid development of an excellent sward by S59 and S170.

(c) The unexpectedly good sward produced, under the prevailing conditions, by meadow fescue.

(d) The superiority of S143 over Trifolium cocksfoot and of S48 over Scots timothy.

Productivity

Estimates of productivity were made at four dates in 1958 and 1959. In Fig. 2 the data have been simplified by grouping into three classes. The categories are based on an average class (class 2) with the mean value of all varieties, for the date in question, as the midpoint and the L.S.D. as the range of the group.

1958

Spring growth was not outstanding in bulk, but the contrast with the natural vegetation was impressive. The following mean heights (in.) taken on 7th May illustrate the situation.

4·7—S170, Trifolium cocksfoot.
4·1–3·7—Trifolium meadow fescue, S24, foxtail, Scots timothy, S48, S143.
3·4–3·2—Yorkshire fog, Danish red fescue, S53.
3·0–2·8—S50, RSMG, S23, S59, SSMG.
2·2—Crested dogstail and bent.
L.S.D. ($P<0·05$)=0·6

Scores indicate that Yorkshire fog was significantly more productive than all other varieties, while the low position of S170 and Trifolium cocksfoot in the classification (Fig. 2) is due entirely to low sward cover. S23 is placed in a higher group than S24 because of the excellent condition of its herbage over the late winter, giving more "keep" on 7 May than the new growth of S24. The latter, timothy and SSMG, were the best varieties in Group 2.

On 2 July, after six weeks rest, observations and sample data show that most varieties contributed 50–60% to the total production of each plot. Due to high standard errors no significant differences were established. S24, RSMG, SSMG, red fescue (especially Danish), dogstail, foxtail and fog all produced a profusion of stems. When grazed in early July these plots tended to be neglected.

On 25 August, the growth was similar on most plots and the differences between classes 1 and 2 were slight. In class 3, foxtail was significantly poorer than the rest. S50 and S23 showed excellent swards, their low productivity being due to some extent to differential hard grazing in early July. The best grasses were markedly superior to the "unsown" treatment.

Autumn production was estimated on 11 October after a six weeks growing period. Despite favourable moisture and temperature conditions, half the varieties were only 2½–3½ in. high, while RSMG, bent, S53, fog, S23 and S50 were <2 in. The high ground cover figures of 60–80% for most varieties, with the exception of Trifolium cocksfoot and foxtail, compensated to some extent for indifferent growth. Yorkshire fog and dogstail were superior to all other varieties; red fescue was also impressive. Colour estimates on a scale 0–5 (5=completely green), are given below.

4·4–4·1—S59, S53 dogstail, Danish red fescue, S50.
3·8–3·5—S48, S170, Trifolium meadow fescue, S24, S23.
3·0–2·6—Yorkshire fog, Scots timothy, SSMG.
2·3–2·1—RSMG, bent, S143.
0·9—Trifolium cocksfoot, foxtail.
L.S.D. = 0·7

1959

By mid March, the experimental area was green and the superior growth of S170 clearly apparent. At the end of April, the amount of growth on many plots was very satisfactory, despite the sward depletion referred to earlier. Average heights in inches are given below.

5·6–5·1—S170, Trifolium cocksfoot.
4·0—Scots timothy.
3·6–3·3—Trifolium meadow fescue, S24, foxtail, S53, S48.
3·1–2·8—S143, S59, dogstail, Danish red fescue, fog.
2·4–2·1—SSMG, S23, S50, RSMG, bent.
L.S.D. = 0·6

In terms of estimated production (Fig. 2) S170 and S59 were significantly better than the rest. Meadow fescue and S50 herbage was particularly green and vigorous. S24 and Trifolium cocksfoot were in the lower category due to thin swards. S23 was disappointing compared with the previous spring and varieties in class 3 were of little value. The drastic deterioration in Yorkshire fog was apparently due to conditions in winter when the herbage became brown and started to rot; recovery was delayed till late in the year.

After grazing, growth was very rapid and by the end of May, S170, Scots timothy and early cocksfoot were 6½–7 in. high, most of the remainder lying between 3½ and 5 in. Together with a marked improvement in ground cover this represented a very satisfactory performance during a three week period when conditions were dry. S170 was the most productive variety in class 1, but the quality of herbage produced by S53 and all timothy varieties was the outstanding feature at the time. Both meadow grasses had a high percentage of leaf burn; S24 and S143 showed signs of nitrogen deficiency not apparent elsewhere.

Grazing, which took place in early June, was uneven, because some plots were more stemmy than others. The plots were therefore cut with sickles, and grazed again in early July. Estimates of late mid-season growth were made five weeks later (on 11 August), at which time the best growth was about 6 in.: the average was approximately 4 in. The improvement in red fescue, cocksfoot and fog was very marked. The meadow fescues continued better than ryegrass. Varieties in class 3, especially RSMG and foxtail, were of little value for grazing.

Early autumn growth was estimated on 6 October: heights in inches are shown below.

4·5–3·6—S170, Trifolium cocksfoot, Scots timothy, Danish red fescue, S143, S59.
2·9–2·3—RSMG, SSMG, Trifolium meadow fescue, dogstail, fog, S48, S53, S24.
2·0–1·3—S50, S23, bent.
L.S.D. = 0·9

The plots were green and vigorous and showed no sign that growth had been inhibited as a result of the dry conditions in August and September. The red fescues were outstanding in the best group; dogstail, as in the previous year, gave its best performance of the season. RSMG stood out in class 2 in which the varieties generally produced a useful amount of herbage. The value of S24 and bent (which was badly discoloured) was negligible and that of foxtail, nil.

Summary of main points

The principal sward development characteristics exhibited by the varieties more or less followed an expected pattern when related to the conditions prevailing.

Under the favourable moisture regime, the best grass swards maintained an impressively high ground cover throughout the period, and together with a small-leaved but vigorous clover growth formed a cover of 80–90%. As a result, especially in mid-season and early autumn, the herbage production was of a good moderate level and of high vegetative quality. Many varieties of high potential were made less valuable in early mid-season because of profuse stem production, notably the red fescues whose development progressively improved throughout 1958 and was always outstanding in 1959. Yorkshire fog overwintered poorly after the first year and did not recover

until August (this was true also of the winter 1959–60).

After a good start, the ryegrasses were disappointing; and throughout 1959 S24 never rose above class 3. The S23 sward looked impressive but did not surpass the meadow fescues whose sustained leafy growth, especially in 1959, was an outstanding and surprising feature at this centre. S53 was the better variety. Crested dogstail was most useful in early autumn in each year, but in this respect, and for winter behaviour it was not as good as red fescue.

Timothy, like meadow fescue, maintained fairly even production of excellent herbage; throughout 1959, S170 was consistently in the highest class. RSMG did not come up to expectation.

B. Birkhill

Early establishment

Sowing took place two months later than at Lephinmore and consequently the varieties were much less advanced by the autumn. Germination was slow and four months after sowing (20 November), though seedlings were abundant on most plots, their average height was less than 2½ in. Even at this stage a slight superiority was apparent in RSMG, ryegrass, cocksfoot and fog. Establishment was most satisfactory in the moister hollows and poorest where loose *Sphagnum* persisted. The recolonizing vegetation consisted of *Eriophorum*, forming a cover of 10–15%. The plants of most varieties were not firmly rooted in the peat, so grazing in the autumn and winter was considered inadvisable.

Sward development

Despite the disappointing start the position in the spring of 1958 was highly satisfactory and ground covers generally compared well with those at Lephinmore. By early June, only S170 and foxtail had ground covers below 40%. RSMG was outstanding, and together with bent and fog, had formed a firm, hoof-resistant sward of 60–70% ground cover.

Further development is illustrated in Fig. 3. Most varieties reached a peak of sward cover in autumn 1958 and then deteriorated over the winter. Ryegrass and the meadow grasses suffered most in this respect. In view of the limited close grazing which the area received, the ground covers, at least of the more successful grasses, were surprisingly high.

The salient features of sward development, after a slow start at this exposed site, were:

(a) The good sward cover formed early in 1958 and maintained subsequently by fog, S143, red fescue and SSMG and, despite deterioration in 1959, RSMG and S48.

(b) The poor overwintering of the ryegrasses and meadow grasses.

(c) The general deterioration in 1959 of S50, bent and dogstail.

(d) The progressive sward improvement of S170.

The relative position of the grass varieties at each site can be seen by comparison of the line diagrams in Figs. 1 and 3. S50, S53 and S23 were rated higher at Lephinmore, but cocksfoot and to a lesser extent Scots and S48 timothy and Danish red fescue were superior in relation to the mean performance at Birkhill.

White clover was prominent in 1959. Sown alone it achieved a cover of 50–80%, while in the grass plots it varied from 20–35%. (RSMG and foxtail plots were clover dominant.)

By autumn 1959 *Sphagnum* had disappeared; *E. vaginatum* formed 20–35% of the grass plots (foxtail 50%).

Productivity

Estimates of productivity have been calculated for three dates in 1958 and four dates in 1959, and are shown in Fig. 4, which is constructed in the same manner as for the other centres.

1958

Over the winter most of the young swards retained a healthy, green appearance and none looked better than S23 and fog. Spring growth was late, and little grazing was available before mid-May.

Owing to difficulties in stocking, the first observations were delayed until 4 June.

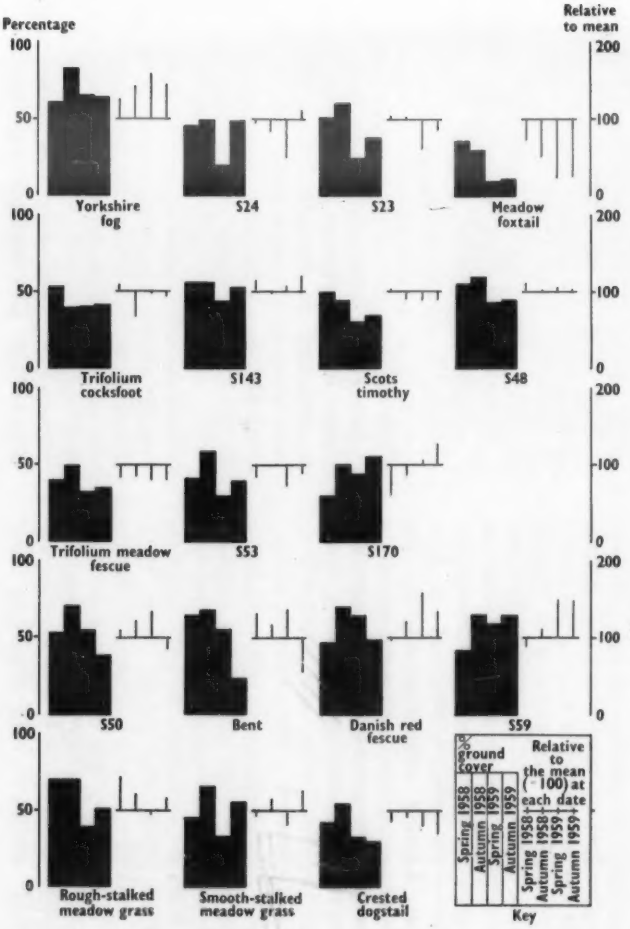

Fig. 3. Birkhill site. Sward development—the contribution of sown grass to the ground cover 1958–59.

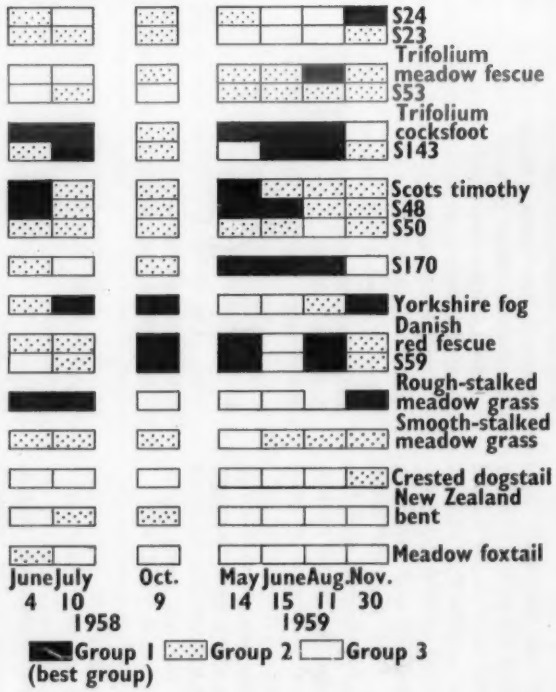

Fig. 4. Birkhill site. Relative productivity—three classes based on the mean at each date. (Full explanation in the text).

Growth at this date is illustrated by the following leaf height figures (in.):

7·7–7·3—Scots timothy, Trifolium cocksfoot.
6·8–5·9—S170, S24, S48, RSMG, SSMG, foxtail, fog.
5·5–4·8—Danish red fescue, S59, S53, Danish meadow fescue, S143, S23.
3·5–2·4—S50, dogstail, bent.
L.S.D. = 1·4

The meadow grasses and dogstail were in head, and the red fescues and S24 were also very stemmy, a tendency which developed earlier than at Lephinmore. The level of production was good but, stemminess apart, the herbage lacked the vigorous appearance characteristic of spring growth in the first harvest year.

In early July varietal differences were not large, and the impression of a general deficiency of nitrogen was emphasized by the green leafy growth around dung and urine patches. Following a light cattle grazing the herbage was cut and removed in early August. Recovery was slow and no further records were taken until 9 October. The height (in.) figures are given below.

8·1—Trifolium cocksfoot.
7·0–6·4—S170, fog, S143, Danish red fescue.
5·9–5·4—SSMG, S59, Scots timothy, Trifolium meadow fescue, S48.
4·8–4·4—S24, S53, S23, foxtail.
3·8–3·1—Bent, S50, dogstail and RSMG.
L.S.D. = 1·8

The outstanding features at the time were the rise to prominence of the red fescue and an improvement in the value of SSMG. RSMG was very disappointing and in common with the bent and to a lesser extent the S24, plots of it contained large brown dead patches. Fungal attack was suspected, but on examination no evidence was found.

The area was heavily stocked with sheep towards the end of November and rested over the winter.

1959

The area became discoloured early in the winter and at the end of February was badly frosted and bare; only RSMG stayed green.

Spring growth was estimated on 14 May and height (in.) classes are shown below:

7·7—S170, Trifolium cocksfoot.
6·0–5·4—S59, Danish red fescue, Trifolium meadow fescue, S24, Scots timothy.
4·9–4·3—S53, foxtail, S48, SSMG.
3·1–2·3—S143, S23, dogstail, fog, S50, RSMG, bent.
L.S.D. = 1·0

The production of Trifolium cocksfoot and S170 was distinctly better than all other varieties. Class 3 (Fig. 4) was of negligible grazing value. The ryegrass and meadow grass swards had decreased markedly in cover during winter, while the Yorkshire fog plots contained large areas of rotting, frost-killed herbage. Dogstail, S23 and bent also exhibited white or brownish patches in the swards. S143 was much later to start growth than Trifolium cocksfoot, and one-third of its herbage was still winter-burnt. The superiority of the meadow fescues over ryegrass was unmistakable in the field.

Cattle were put on the area on 22 May, but the poorer plots were neglected. Early mid-season growth was estimated on 15 June. The previous rest period had been very dry and red fescue, dogstail and RSMG were rather stemmy. The varieties in class 3 were burnt in appearance, and only class 1 had any real grazing value.

In the absence of stock, the plots were mown on 14 July. Field notes indicated that little if any growth had taken place during the month. Most of the herbage looked burnt and in need of nitrogen. Clover, on the other hand, was growing strongly but with no apparent benefit to the associated grass.

Wider varietal differences had developed by mid-August and cocksfoot was significantly better than all other grasses. The value of those in class 2 was limited and that of class 3 was nil. In fact, the most useful production on most plots in these groups was given by clover which reached a peak at this time, and was particularly abundant in the RSMG plots. Only cocksfoot, red and meadow fescues and SSMG had a satisfactory colour while the

three timothy varieties were apparently suffering from drought.

Conditions were very dry until October and November when rainfall was heavy. Growth was slow throughout the period and many varieties did not respond to the more favourable moisture conditions. Yorkshire fog, S24 and RSMG, however, showed a marked improvement and their growth was satisfactory for both leafiness and colour, as, to a lesser extent, were S23, S50 and dogstail. Cocksfoot and S170 were already badly burnt while Scots and S48 timothy did not recover as well as S50 after the late summer drought. Class 3 varieties were of little value while in class 2 only S23, the red fescues, SSMG and S50 were producing enough to be of some immediate use.

Summary of points

The Birkhill site received much less rainfall than Lephinmore although the difference was not so marked in the period April-November. The difference in moisture regime of the peat was accentuated by the exposure of the Birkhill centre to almost continuous drying winds and the peat surface was dry over much longer periods. The winter was also longer and harder. It is not surprising that, at Birkhill, growth was much later in the spring, vegetative quality was poorer and the tendency to run to stem was more marked. Even more outstanding was the rapidity with which the herbage became non-vigorous and yellow in colour.

Although the lack of intensive grazing for long periods undoubtedly prevented optimal performance, many varieties still produced sward covers as good as, or even better than, at Lephinmore. Differences between the varieties were very great in 1959, but only a few of them were able to maintain a level of production comparable with that at Lephinmore.

Comparisons of production classes can be made from Figs. 2 and 4. Many similarities in relative performance result from the reaction of fog, ryegrass and meadow grass to the winter period of 1958–59. The notable difference lies in the better relative performance of cocksfoot at Birkhill. (This, however, could not compare with that of timothy at Lephinmore.) The other outstanding varieties were timothy, S170 and red fescues. The superiority of meadow fescue to ryegrass for most of the time was an interesting feature of the results.

ACKNOWLEDGEMENTS

The authors are indebted to the late Dr. John Smith and to Mrs. Smith for the facilities and encouragement to conduct the work at Birkhill. Thanks are due to Mr. D. C. Currie, Farm Manager, Lephinmore, and his staff for supervising the grazing of the plots sited on the farm, and to many colleagues in the Botany Department for assistance at various times.

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BOOK REVIEW

M.A.F.F., Bulletin No. 154. **Grassland Management.** 3rd edn, 1960, pp. 74, bibl. 27, 24×15 cm., London: H.M.S.O., 4*s.* 6*d.*

The first two editions of this bulletin were published in 1952 and 1955. Its full ancestry goes back to Misc. Publ. No. 24, *The Improvement of Grassland*, issued in 1920. The titles of the 8 chapters are unchanged and proceed from general considerations of cultivation and management, through various types of farm and hill grazing, to a final appraisal of grassland and crop potential. Although grassland studies have made great progress in recent years, there are surprisingly few changes in the text. But those that have been made are significant. About a third of them occur in the chapter on 'Mixed farms: cattle and sheep', which now appears under the authorship of Dr. T. H. Davies, successor at Exeter to the previous author of this chapter, Dr. W. E. Jones. The advent of the rotary mower, swipe, and forage harvester account for a good many revisions. Increasing use of the rotavator for breaking turf, and of chemicals for killing weeds or even the sward itself, account for some others. In the ever-widening realm of chemical fertilizers there is a new paragraph on magnesium, inserted confusingly (and presumably in error) between two paragraphs on nitrogen. Nitrogen itself receives much more emphasis, although mention of 'nitro-chalk' has largely disappeared. All seeds mixtures have been brought up-to-date, and there are changes in practice relating to rotations, the use of foggage, and of 'self-help' silage. Several changes in the wording of sentences betray a growing concern about the dangers of winter grazing, either because the soil is liable to become poached, or because the sward becomes exhausted and takes a long time to recover. This bulletin is written for readers in Gt. Britain and very naturally tends to be insular in outlook. It would gain greatly in stature and interest if there were more references to grassland management practice in other parts of the world, if only for the sake of comparison. This deficiency is redressed to some extent in the final chapter on grassland and crop potential. Even here, in the section on sward differences and fertility, which has been largely rewritten, it is surprising to find no mention of the mobilization of minerals from depths by deep-rooted plants reported from other countries. Perhaps the quantity of (impure) chemical fertilizers used in Gt. Britain deprives this effect of practical interest. Of very great significance is the shift in emphasis from humus and structure towards nitrogen (when other minerals are adequate) as an explanation of the fertility status of soils. In this connexion the reference to work in Uganda might be revised to say that crumb structure built up by grasses is rapidly broken down by cultivation, whereas the effect of organic manures on subsequent cropping is profound. Even though the price has risen by half since the last edition, this bulletin is excellent value for money.—J. D. JAMESON. From *Herbage Abstracts.*

ABSTRACTS

WESTENDORP, T. [**Bruising newly-mown grass during haymaking.**] *LandbVoorl.* 1961, **18,** No. 1, 28–32, illus.

During 1959 the effects were investigated of various types of machinery on the curing of hay crops from a 1-year ley. Tedded crops dried twice as quickly as crops cured in the swath. Mowing and crushing the grass, either as one simultaneous or two consecutive operations dried the crop 4 times as quickly as in the swath. Crops passed through a crusher-spreader after mowing dried 1·5 times as quickly as tedded crops. Neither crushing nor tedding adversely affected the chemical composition of the hay. Haymaking by hand and machine tedding caused similar dry-matter losses. Losses were slightly, but not significantly, greater where a crusher-spreader was used. Machinery which mowed and crushed the crop in one operation could not be recommended, since it caused considerable dry-matter losses, and much material [about 7%] became lodged in the stubble and could only be removed by raking.—R.B. From *Herbage Abstracts.*

ADALSTEINSSON, S. and others. Ahrif fergingar á verkun votheys. [**Effect of pressure on silage quality.**] *Atvinnudeild Haskolans Rit Landbunadardeildar, A-Flokkur* 1960, No. 13, pp. 35, bibl. 20, English summary. [Univ. Res. Inst., Reykjavík, Iceland]

Unchopped unwilted aftermath [mostly *Festuca rubra* and *Poa pratensis*] was ensiled without additive (a) without compression, (b) compressed with concrete bricks at 700 kg/m², (c) and (d) compressed with 2 types of pressure equipment at 1300 and 3000 kg/m², respectively. The silos used measured 3 m. square for (a) (b) and (c) and 2·5 m. square for (d), and were 6–6·7 m. tall. A fifth silo (e) 16 m. high and 5 m. diam. was filled with

chopped unwilted first cutting herbage for comparison. The results were as follows: maximum temperature during fermentation, (a) 51°C, (b) 31°C, (c) 32·1°C, (d) 24·4°C; pH (a) 4·73, (b) 4·83, (c) 4·77, (d) 4·21, (e) 4·15; % dry matter, (a) 23·9, (b) 28·2, (c) 24·7, (d) 26, (e) 26. The pH in silos (d) and (e) was significantly lower than in the other silos. Data on organic-acid content indicated that (e) was the best silage, closely followed by (d). The other silages were of poor quality. Digestibility of crude protein decreased significantly more during ensiling in (a) (b) and (c) than in (d). The feeding value of dry matter in silage as a percentage of that of the original grass significantly decreased with increasing silage pH. Under optimum conditions for lactic-acid production little butyric acid was produced, and *vice versa*. When the content of lactic acid was expressed as a percentage of total milli-equivalents of acids, about 59% of the variation in pH could be explained by variation in the relative amount of lactic acid. Results indicated that high pressure was necessary to obtain good quality silage from unchopped aftermath without using additives. F. Eng.—R.B. From *Herbage Abstracts*.

MUDD, C. H. AND MAIR, R. B. **Performance of eight seeds mixtures at Great House—1952-58.** *Exp. Husb.* 1961, No. 6, 21–50, bibl. 4. [Great House Exp. Husb. Farm]

Six simple mixtures each consisting of a hay or a pasture type of cocksfoot, perennial ryegrass or timothy + white clover and 2 complex mixtures (Cockle Park and timothy/meadow fescue) were sown at 2 sites in the Pennines in 1952 and 1953. Each plot was given 1 of 4 management treatments each year for 6 yr: (a) grazed only (b) grazed and mown (aftermath grazed) in alternate years (c) mown and aftermath also mown (d) mown and aftermath grazed. Detailed results are given of dry matter and protein yield and of botanical analyses. It was concluded that: (1) S48 timothy + white clover was the outstanding mixture for grazing. (2) The most consistently high yields of hay were given by a mixture of S215 meadow fescue, S48 timothy and S143 cocksfoot + white clover. Reasons for the failure of perennial ryegrass are discussed.—R.H.F. From *Herbage Abstracts*.

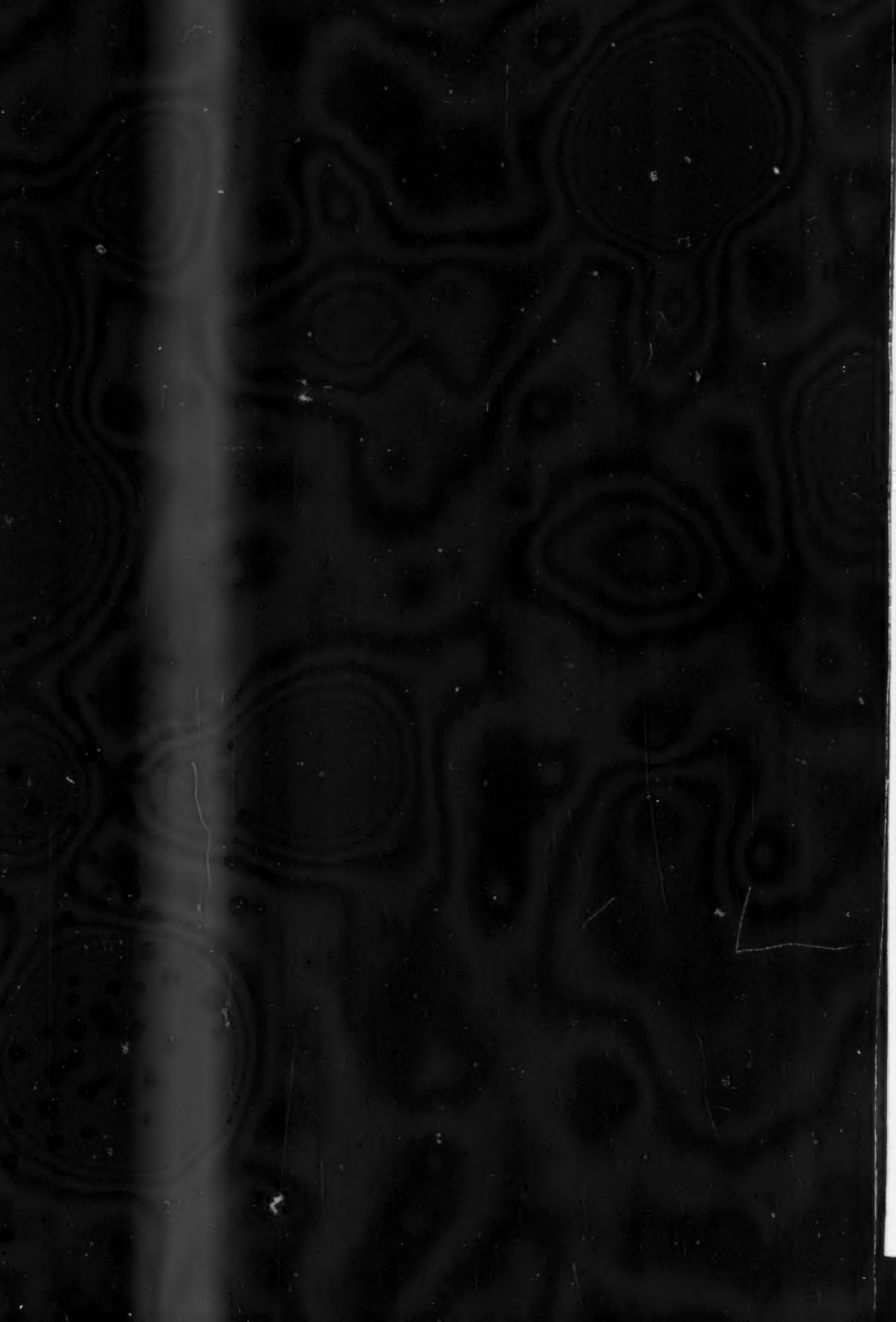
REITH, J. W. S. and others. **The effects of fertilizers on herbage production. 1. The effect of nitrogen, phosphate and potash on yield.** *J. agric. Sci.* 1961, **56,** No. 1, 17–29, bibl. 10. [Macaulay Inst. Soil Res., Aberdeen]

Factorial experiments were carried out at 6 centres in Scotland, in 1953–5, to measure the effects of N, P and K on dry-matter yield, and to determine the effect of N on the P- and K-requirements of grass cut 5 times per year for conservation. Heavy dressings with N reduced the percentage dry matter in the fresh herbage, but increased greatly the yield of dry matter. There were large variations in the response to N, but 348 lb. N/ac./year increased yield by 70–140% and generally the response curves were substantially linear. The response to N depended on an adequate supply of K and at 5 of the centres there were large interactions between these 2 nutrients. The need for K was greatest at the highest rate of N and was much greater in the 2nd and 3rd years than in the 1st. At the highest N rate some of the responses to K were very great (up to 46 cwt. dry matter/ac.). There were no great or consistent differences in yield from applying 336 lb. K_2O/ac. in one dressing in winter or this amount in 5 equal dressings, one for each cut. The results demonstrated the ability of the soils to supply K and showed that regular cutting and removal of herbage exhausted the K reserves in the soil, especially if heavy dressings of N were applied. Phosphate had practically no effect on dry-matter yield in either the presence or absence of N. With adequate K, the production of dry matter per lb. of fertilizer N was practically independent of rate of N and averaged 14–15·7 lb./ac. In the absence of fertilizer K, there was a large effect of rate of N. In this case dry-matter production/ac./lb. N was 15 lb. with 87 lb. N/ac./year, 13·7 lb. with 174 lb. N and 10 lb. with 348 lb. N. About 70–75% of the annual production was obtained before the end of July. Thus 1 lb. of fertilizer N produced considerably more dry matter per ac. during May-July than later in the season. F.s.—A.M.H. From *Herbage Abstracts*.

REID, D. **Factors influencing the role of clover in grass/clover leys fertilized with nitrogen at different rates. 1. The effects of the variety of companion grass on the yields of total herbage and of clover. 2. The effects of the variety of white clover on the yields of total herbage and of clover.** *J. agric. Sci.* 1961, **56,** No. 2, 143–60, bibl. 25. [Hannah Dairy Res. Inst., Kirkhill, Ayr, Scotland]

During 1955–7, 3 N treatments, 0, 4 and 10 cwt. nitro-chalk (15·5% N)/ac./season, were applied to 21 grass/clover mixtures sown in the spring of 1954. The mixtures contained either S184, S100 or Kersey white clover alone or in association with one of the following grasses: S23 or S24 perennial ryegrass, S143 or S37 cocksfoot, S48 timothy or S53 meadow fescue. The greatest yields of mixed herbage were obtained from mixtures containing S24 perennial ryegrass, while the greatest yields of clover came from those containing S53 meadow

fescue. The smallest yields of both mixed herbage and of clover were obtained from mixtures containing S143 and S37 cocksfoot. It is shown that the value of clover in a mixture and the response of that mixture to N varied with the particular grass it contained. S143 and S37 cocksfoot were poor companion grasses for clover, but mixtures containing these grasses responded well to fertilizer N applications, while the reverse occurred with S53 meadow fescue; the other grasses tested were intermediate. The variety of clover included in the seeds mixture was of minor importance compared with the variety of grass in determining the response of the mixture to N applications, and in determining the contribution of clover to total yield within each N treatment. Averaged over all N treatments, the yielding ability of a seeds mixture appeared to depend to a greater extent on the variety of grass than on the variety of clover included in it. F.s.—E.B.O. From *Herbage Abstracts*.



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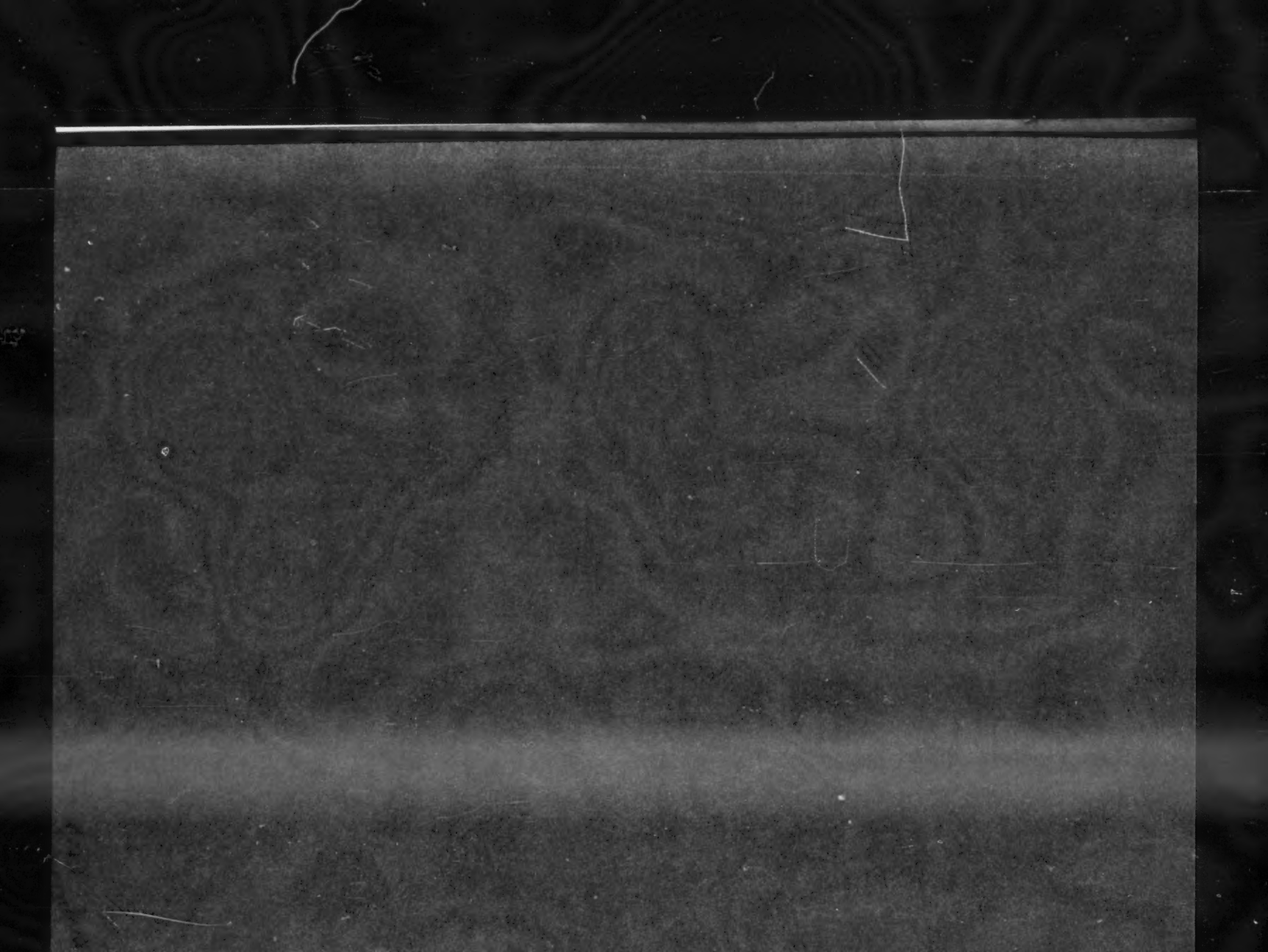
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